CHAPTER 2

Pressure Sewer Systems

2.1 Introduction

2.1.1 Background

Historically there have been only two choices for the disposal of domestic wastewater: either conventional sewers were used, usually having lift stations as needed within the system, and discharging to municipal treatment works, or septic tanks and drainfields were used. Conventional sewers were generally used in cities and larger towns, and septic tanks and drainfields were more common in rural areas.

These technologies are mature and time honored, but there are cases where neither method is well suited. Where rock excavation is encountered the deep excavations for conventional sewers can result in excessive costs. Similar obstacles to conventional sewer construction include high groundwater, and terrain that does not slope favorably for gravity collection. Where homes are spaced distantly the resulting long length of sewer between homes results in unacceptably high costs.

Septic tank drainfields encounter difficulties when located in tight clay soils that have low absorption rates, or in areas of high groundwater. In these cases effluent often surfaces above the drainfields. Where soils are too porous the effluent may flow too freely and enter the groundwater without sufficient treatment.

In instances such as described above, pressure sewers and other alternate technologies should be considered.

2.1.2 History

Lift stations have long been used with conventional sewers, and occasionally household pumps having solids handling capabilities have been used to lift wastewater from low lying homes to conventional sewer mains. Pumps have long been used to discharge effluent from septic tanks to distant or elevated drainfields, but until the last 15 years there has been no widespread use of pressure sewer systems.

Mortimer Clift was among the first to report on pressure sewer technology regarding a system serving 42 homes in Radcliff, Kentucky.[1] Solids handling pneumatic ejectors were used which discharged via 7.5-cm (3-in) diameter service lines to a 10-cm (4-in) main, following the concepts of a patent issued to him in 1965. The system was eventually abandoned due to equipment problems, but no uncorrectable obstacles were apparent regarding the pressure sewer concept.

With concern for the limited capacities of the numerous combined storm - sanitary sewers existing in the United States., Gordon M. Fair proposed a solution announced publicly in 1965. Fair suggested conveying domestic wastewater in a pressure sewer main separate from storm water, with the main being hung from the crown of the existing combined sewer. His patented "converted sewer system", issued in 1968, was assigned to the public.

Fair's proposal prompted a study of the concept by the American Society of Civil Engineers (ASCE), for the Federal Water Pollution Control Administration. During this time General Electric subcontracted with the ASCE to develop a grinder pump package following the directives of the ASCE engineers. The final report, published in 1969, concluded unfavorably toward the concept due to costs associated with placing a sewer within a sewer, but the pressure sewer concept using grinder pumps was otherwise endorsed.[2]

Paul Farrell was a project engineer with General Electric and was highly involved in the ASCE study and in development of the grinder pump package. He continued his efforts with a pressure sewer demonstration project in 1970 at Albany, New York, which served 12 townhouses. This was probably the most extensively monitored system ever built, and was the subject of detailed and thorough analyses[3].

General Electric withdrew from further involvement while Environment-One Corporation continued the grinder pump development and went on to other demonstration projects, such as Grandview Lake, Indiana, which served 93 homes. Mr. Farrell is still with Environment-One Corporation. Other pioneers in pressure sewers included Harold Schmidt, who proposed the use of septic tank-effluent pump (STEP) pressure sewers. His first STEP installation was made serving subdivision homes in Port Charlotte, Florida, in 1970. That system now serves over 1,000 homes. Ken Durtschi also proposed a STEP pressure sewer system to serve over 500 homes at Priest Lake, Idaho. With his design and under his direction, the system was built in the early 1970s. Gary Klaus also proposed a system that involved the use of a solids handling pump which discharged via a flexible hose to a pipeline mounted on the dock. The wastewater was conveyed from there to a floating septic tank which discharged chlorinated effluent to the river. Beginning in the early 1970s, Cecil Rose, then chief engineer for the Farmers Home Administration, became a proponent of pressure sewers, especially those conveying septic tank effluent.

USEPA's Office of Research and Development provided support for several early demonstrations of pressure sewers, including Grandview Lake; Indiana, Phoenixville, Pennsylvania; Albany, New York; and Bend, Oregon.[3-6] Subsequently, the Agency produced a Small Community Technology Transfer Seminar series which included a report on pressure and vacuum sewer systems in 1977.[7]

When the Clean Water Act of 1977 gave increased Federal funding to all projects that incorporated these alternative collection systems, the number of documented installations proliferated in the United States from approximately 100 to more than 600 by the end of the Construction Grants Program in 1990. This number may be significantly larger today if all the systems not funded by the Federal Government are also included. Of the documented total, pressure sewers constitute the most numerous class, followed closely by small diameter gravity sewers; vacuum sewers systems are well behind.

2.2 Detailed System Plan and Elevation Views Showing Locations(s) of All Components

A simplified sketch showing a section of pressure sewer main is shown as Figure 2-1. In the figure, discharge is presumed to a treatment and disposal facility. If discharge is made to a conventional sewer, pretreatment facilities may be required.

Pretreatment facilities are located and sized in accordance with the contact time required for the particular method of pretreatment. For example, chlorine reacts almost immediately whereas aeration may require several hours. Another parameter dictating pretreatment station location is the flow regime in the main. For example, air injection into a main could only be feasible if the main were steeply rising, and if there were substantial pressure in the main to cause the dissolution of oxygen into the waste stream.

Isolation valves (IVs) are located about the same as in water line practice. At the intersection of mains two IVs are usually placed as shown in the figure, although some engineers prefer using a valve cluster of three IVs. Isolation valves are sometimes placed at the upstream end of mains, to facilitate subsequent main extensions.

IVs are also placed on each side of areas where subsequent disruption of the main can be anticipated, such as at bridge or stream crossings, where future road construction is foreseen, or in areas of unstable soils. Where reaches between IVs become long, intervening IVs are sometimes used to divide the long reach into shorter lengths.

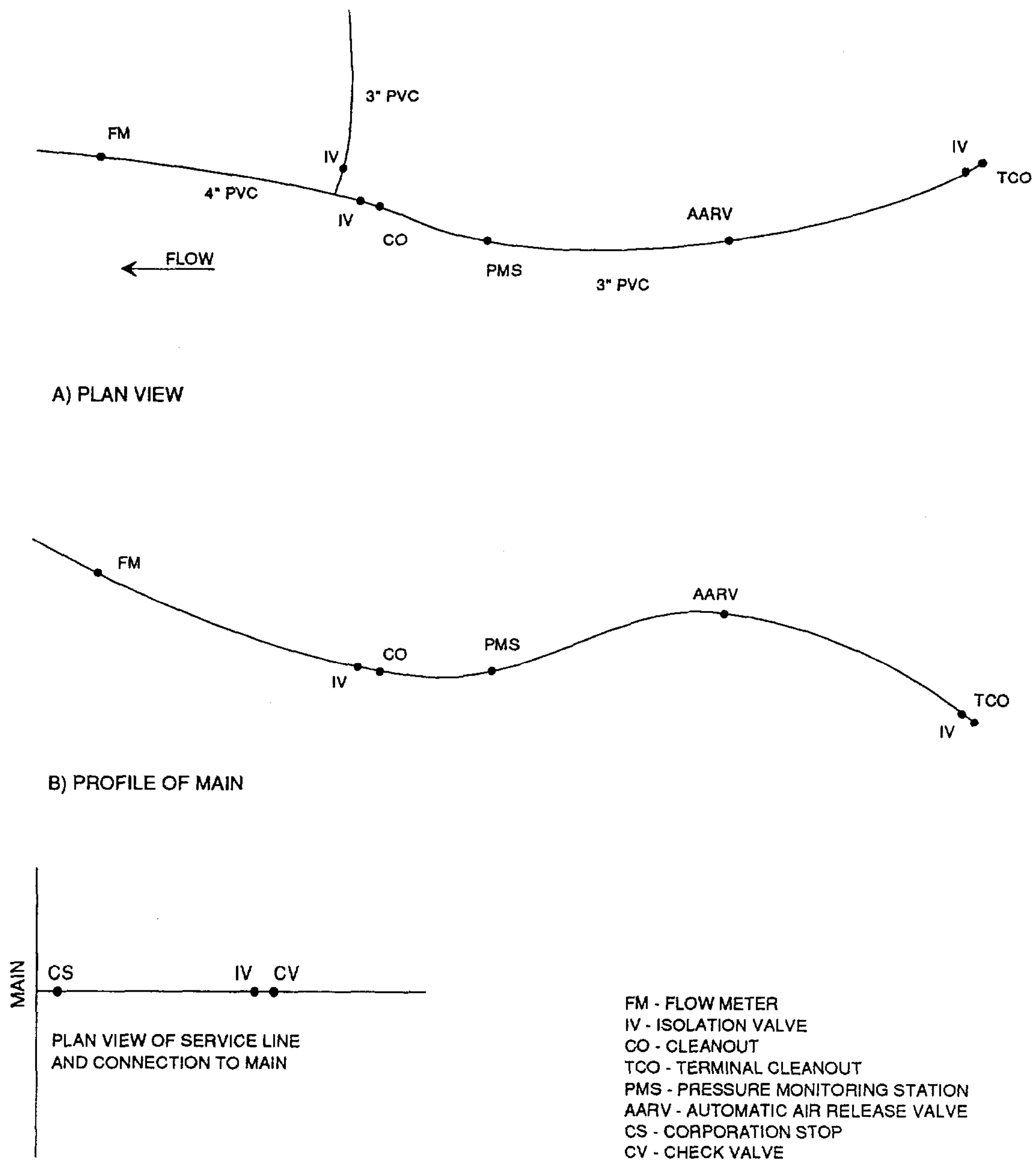
On long, steep grades, IVs are located to accommodate pressure testing requirements. Other IVs may be used as a part of the design of other facilities, such as with cleanouts or with flow meters.

Cleanouts (COs) are sometimes provided and when provided, in-line cleanouts are most typically placed where pipe sizes change. This is in anticipation of cleaning the main using a pipe cleaning pig. Terminal cleanouts (TCOs) may be located at the ends of mains. If the design of the cleanout is such that it rises to ground surface, a manual or automatic air release valve is often fitted to the high point.

Air release valve stations may be manual (MARV) or automatic (AARV). When the main is submerged under a static head the air release valves are normally located at summits. If the upstream end of a main terminates on a rising grade, an air release valve is used there. In two-phase flow regimes the air releases are placed as described elsewhere. A soil bed or other facility for odor absorption is sometimes provided at AARV stations, especially if located where odors would be a nuisance or if the particular station is expected to release much gas.

Service saddles, tees, or tapped couplings are used to join the service line to the main. A corporation stop is often provided there, and a check valve if the main is accessible. An isolation valve and check valve may be provided on the service line, sometimes located at the

Figure 2-1. **Piping system appurtenances.**



road shoulder or at the road right-of-way line. The location is chosen based on anticipated damage caused by such activities as road grading or snow plowing, and based on subsequent accessibility. For example, service line IVs and CVs are usually located outside of paved areas.

Flow meters are valuable, particularly when assessing capacity of the system and when quantifying the extent of I/I the system receives. They are also used to flow-pace pretreatment facilities using chemical injection. For economic reasons, however, they are often not provided. They are generally of greater benefit on larger systems serving several hundred homes but should be considered for small systems as well. Most large systems use permanent installations. In smaller systems portable meters may be used to determine flows at particular points in question.

Pressures within the system can be measured in the GP or STEP pump vault if the discharge piping will accommodate the meter, and providing no check valve is used between the gauge and the main. However, most systems use service line check valves, which precludes this practice and makes necessary the provision of pressure monitoring stations (PMS).

Pressure monitoring stations are simple, inexpensive, and should be provided on systems where there may be questions as to operating conditions. The recording pressure gauge is usually moved from station to station as needed. PMSs can help reveal air-caused headlosses, and unexpectedly high or low flows. This is done by comparison of the theoretical hydraulic grade line versus that measured.

2.3 Detailed Description of On-Lot System Components

2.3.1 Available Systems

The pressure sewer pumping unit periodically discharges flow from the home or homes served to a pressure sewer main where the flow is conveyed to a point of treatment and disposal.

With a grinder pump (GP) system, the purpose of the grinding action is to reduce the size of troublesome solids present in wastewater making a pumpable slurry to be conveyed in the small diameter service lines and mains.

Solids handling (SH) systems rely on user cooperation to ensure that particularly troublesome solids are not discharged to the pumping unit. Such matter includes hard solids, plastics, rags, sanitary napkins, and stringy material.

Effluent pumps (STEP) are merely open-impeller pumps which are capable of pumping wastewater from which troublesome solids have been removed by the septic tank.

2.3.2 Detailed Descriptions

The septic tank of a STEP system captures most grit, grease, and other troublesome solids, and retains the sludge and floatable matter. The effluent is also reduced in strength in terms of BOD, SS and certain other parameters. This is of major benefit when drainfield or sand filter treatment is used, and may be a secondary benefit when mechanical forms of treatment are used.

The pump vault provides storage for a working volume between the "pump on" and "pump off" liquid levels, so the pump does not cycle on and off too frequently. The storage volume between "pump on" and "high level alarm" allows the inflow rate from the home to temporarily exceed the discharge rate of the pump without triggering an alarm.

The "reserve space" between the high level alarm and the point where the pump vault is full and overflow is impending is particularly important. A small reserve space volume will not store sufficient flow to avoid overflow or backup in the home, causing inconvenience to the user prior to the time that service personnel can arrive and correct the malfunction.

When STEP systems are used the reserve space provided by the septic tank is usually quite large, in the order of one day's average flow, which allows the service personnel to attend to maintenance calls less urgently.

Emergency overflows are sometimes provided when grinder pumps are used owing to limited storage capacity of the pump vault. When using STEP systems the septic tank encompasses a large storage volume above the normal water level and such overflows are rarely required. However, overflows can be easily disposed of to the drainfield. The raw wastewater overflow of GP or SH systems should go to a drainfield via a septic tank or be discharged to a holding tank. Any overflow management should be limited to short-term emergencies and should not permit inflow back into the system.

Pump manufacturers provide preassembled packages of pressure sewer components, including the pump, pump vault, in-vault piping and valves, liquid level sensors, electrical control panel, electrical junction box, and associated equipment. The availability of such packages greatly simplifies the duties of the application engineer, and often has the distinct advantage that the assembly has been refined as dictated by prior experience. There is also a single source of responsibility in the event of malfunction.

In some cases, component systems have been designed by the application engineer and built by the owner or the contractor's supplier. There have been two distinct motives for the site-specific component approach. One is economic: the assembly can often be produced at less expense if the components are purchased separately and assembled by the owner or contractor. However, inferior components are often used, the components selected may not work well together, and quality control has been known to suffer.

The second reason site-specific component systems have been used has been the view that a better system can be built, custom made for the particular project needs. This approach has been successful on only a few projects where prototypes were fully developed, tested and refined over a period of time, or where the design engineer had considerable experience with pressure sewer technology.

A typical simplex GP package is shown in Figure 2-2. The pump vault is typically fiberglass and usually 60-90 cm (2-3 ft) in diameter. The depth varies with the dictates of ground topography and the volume of reserve space to be provided. Typically specified depths of basins are usually 1.5-2.4 m (5-8 ft).

The pump is shown to be suspended, and aligned with a slide-away coupling by guide rails. This design has historically been favored by most centrifugal pump manufacturers. A long-handled operating wrench is used to reach the shutoff valve from ground surface. A lifting chain is provided to aid in removing the pump.

Three mercury-float-switch liquid level sensors are within the pump vault: "Pump off", "pump on", and "high level alarm". In some cases a redundant off float is added, which may not only stop the pump but sometimes activates a low level alarm. If a duplex installation is made, an additional float switch is used for the lag pump-duplex cycle.

Wiring is extended from the electrical junction box in the pump basin to an electrical control panel. The control panel is usually mounted on the outside wall of the home, but in some cases it is pedestal mounted adjacent to the basin.

Figure 2-3 shows a centrifugal grinder pump suspended from the basin cover, rather than using the guide rail-slide away coupling arrangement. This system is intended for installation within the home, often in a basement. A duplex grinder pump station is shown in Figure 2-4.

One popular semi-positive displacement (SPD) grinder pump package differs considerably from the centrifugal pump GP packages shown previously. A typical design is shown in Figure 2-5.

The progressing cavity type of semi-positive displacement pump is suspended into the basin. The pumping core is comprised of the pump, motor, grinder, piping, valving, and electrical controls. Liquid levels are sensed using a trapped air type of pressure sensor, somewhat like a bubbler system, but without the compressor. This system has no moving parts in contact with the wastewater. The components are shown in Figure 2-6.

An external control panel is not needed with this type of pump, but an external branch circuit disconnect is sometimes used, and an external high level alarm annunciator (horn or light).

Figure 2-7 depicts a STEP pump in a pump vault external from the septic tank. Some GP installations are the same and would only vary in that the pump has a slightly different appearance. When a GP is used as shown in this figure, stainless steel legs are screwed into the bottom of the pump since most GPs are made to be suspended.

This installation does not employ guide rails. Instead of connecting the discharge via a slide away coupling, a discharge hose is used which extends to within a few inches of the top of the basin where a quick-connect coupling and the isolation valve can be reached from ground surface. This is the type of installation usually favored by makers of GP component systems. STEP systems are usually of a different type, shown below.

SH systems are typically as shown in Figure 2-7.

A STEP system is shown in Figure 2-8. This concept employs a pump vault internal in the septic tank, as contrasted against the external pump vault shown in Figure 2-7. Both approaches are widely used for STEP systems.

The effluent pump rests on the floor of the pump vault, and discharges via a flexible discharge hose that connects to the service line piping with a quick-connect coupling near ground surface. Three mercury float switches are used, and an external electrical control panel (not shown) is employed, as in GP practice.

Figure 2-2. Typical simplex GP package using slide away coupling and guide rails. (Courtesy F.E. Myers Pump Co.)

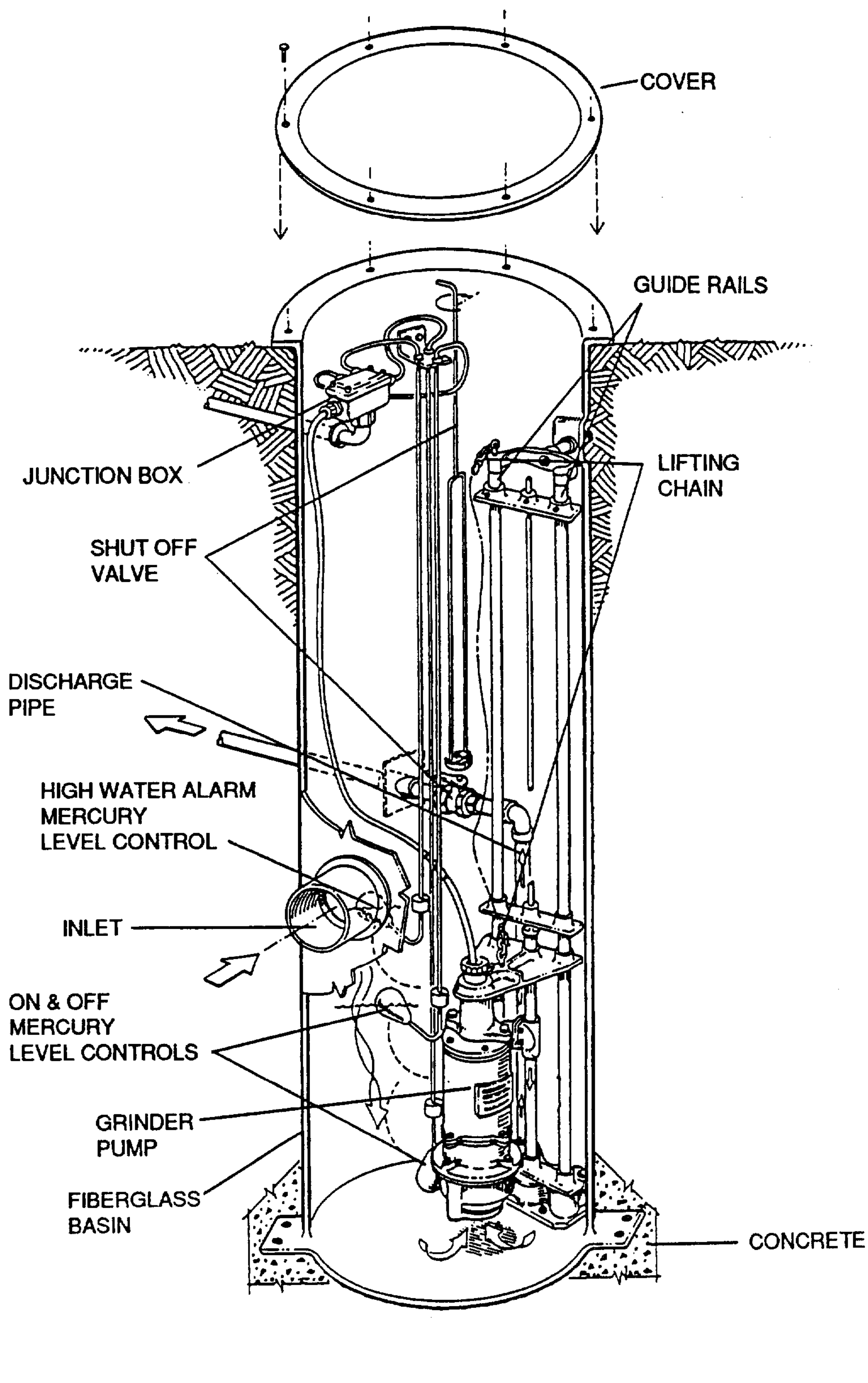


Figure 2-3. Typical centrifugal GP package with pump suspended from basin cover. (Courtesy Barnes Pump Co.)

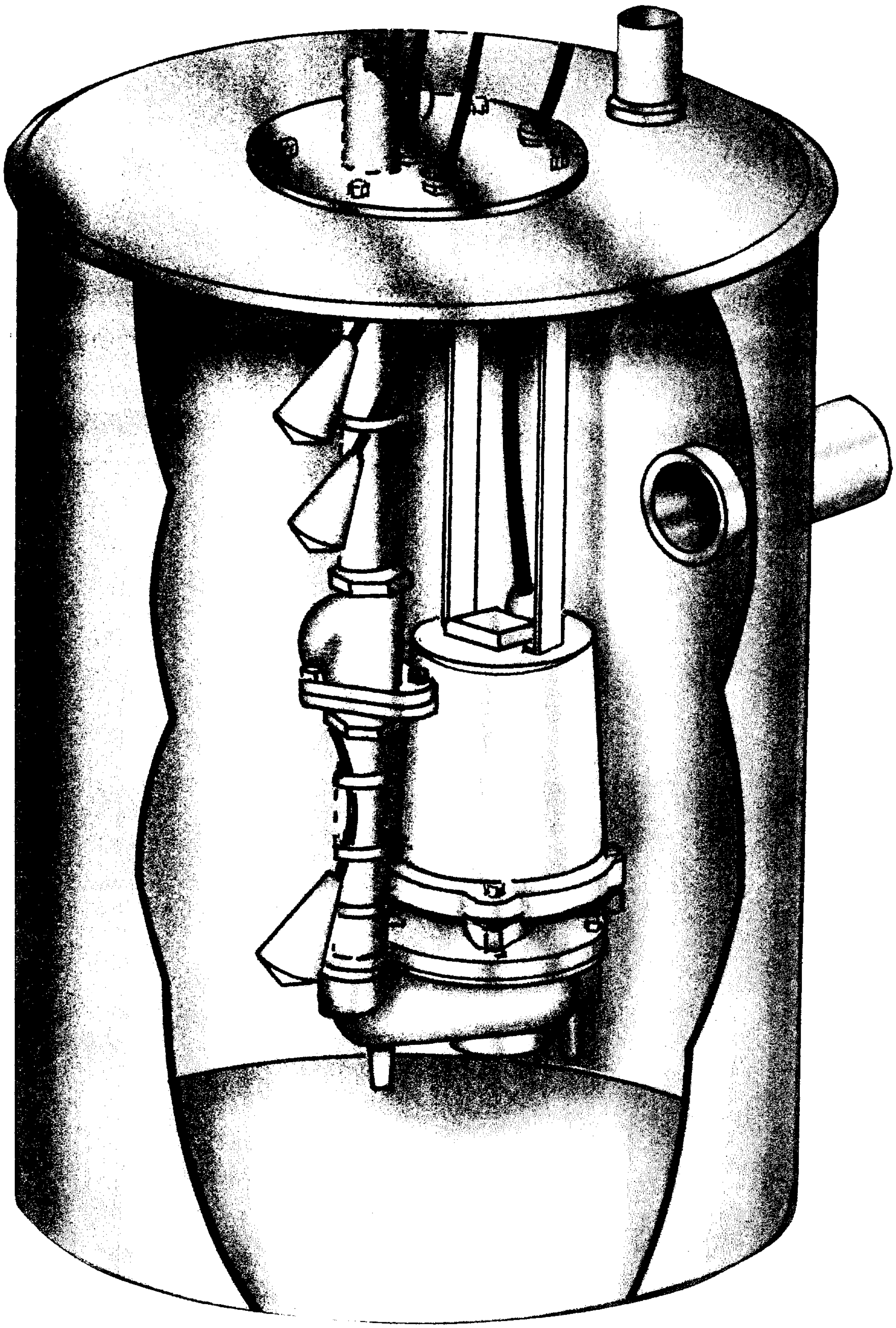


Figure 2-4. Duplex GP station. (Courtesy Barnes Pump. Co.)

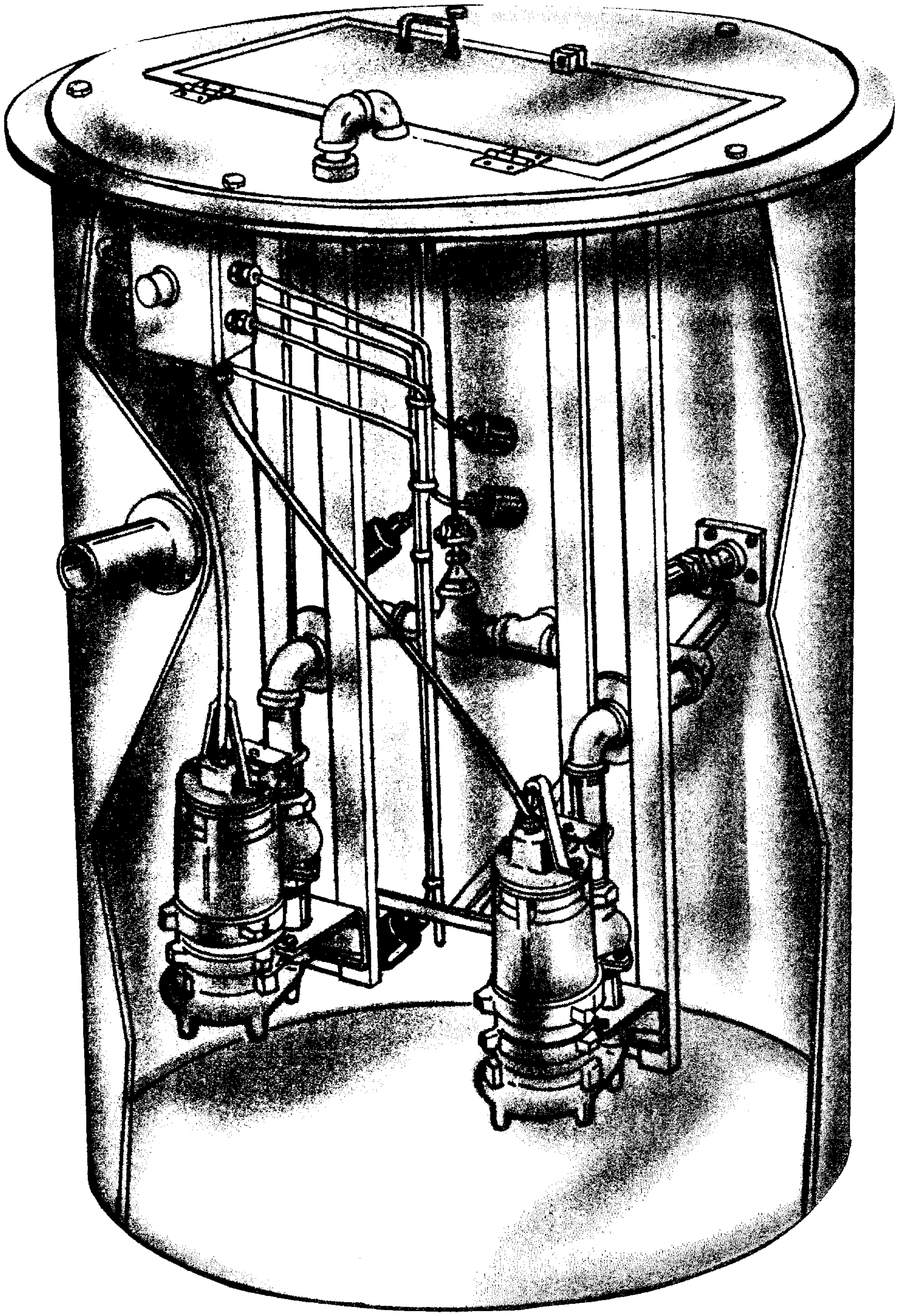


Figure 2-5. Typical progressing cavity-type GP package. (Courtesy Environment/One Corp.)

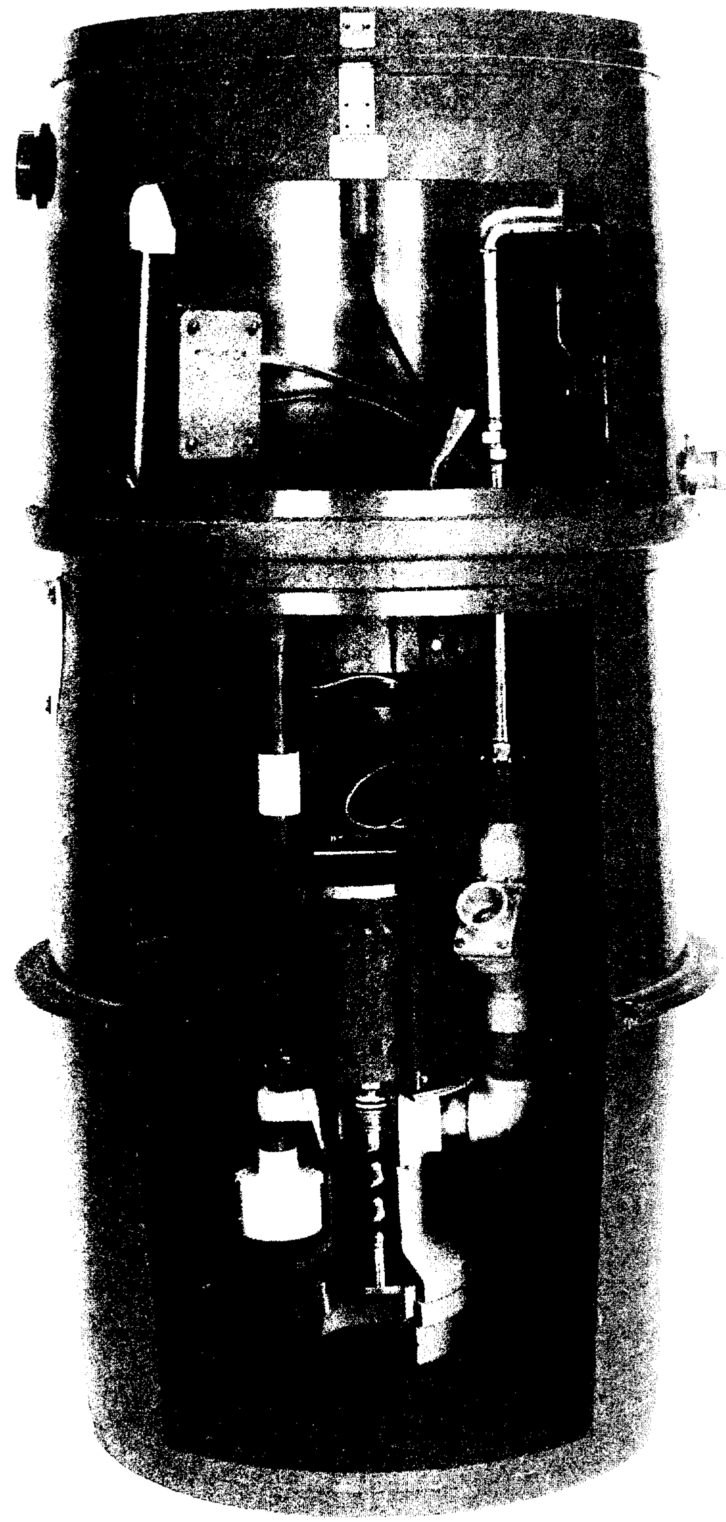


Figure 2-6. **Basic components of a progressing cavity grinder pump. (Courtesy Environment/One Corp.)**

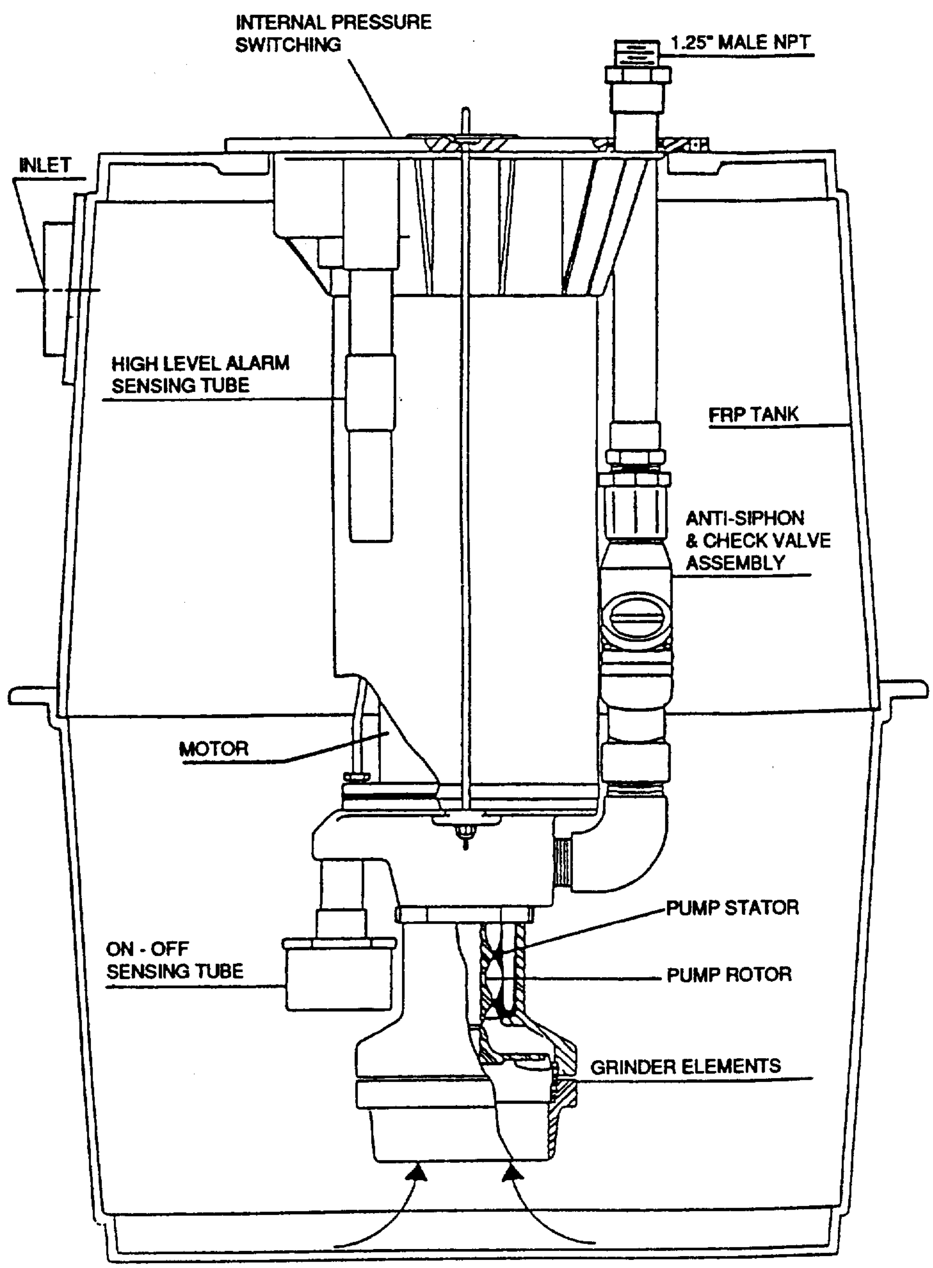


Figure 2-7. STEP pump in external vault. (Courtesy Barnes Pump Co.)

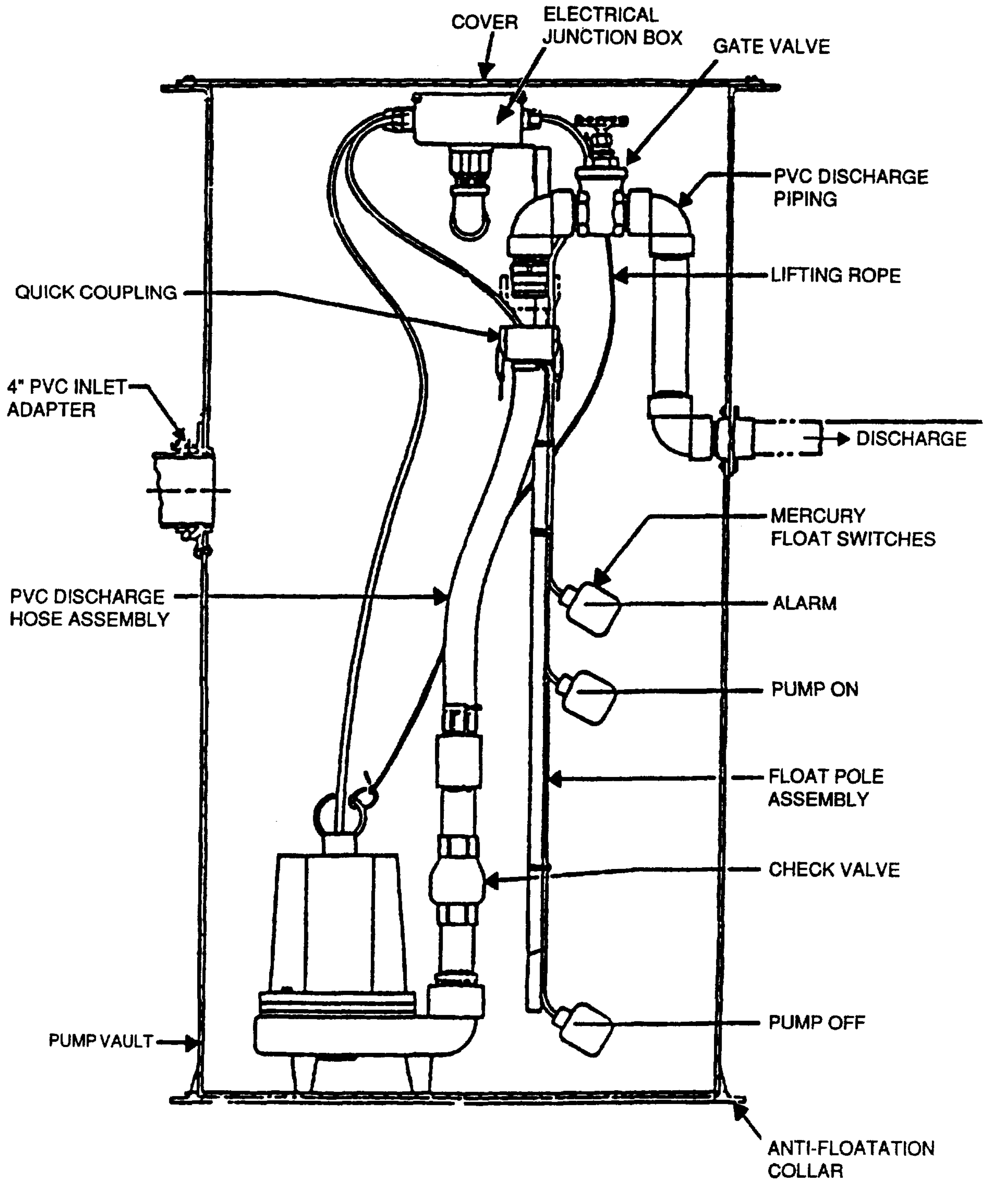
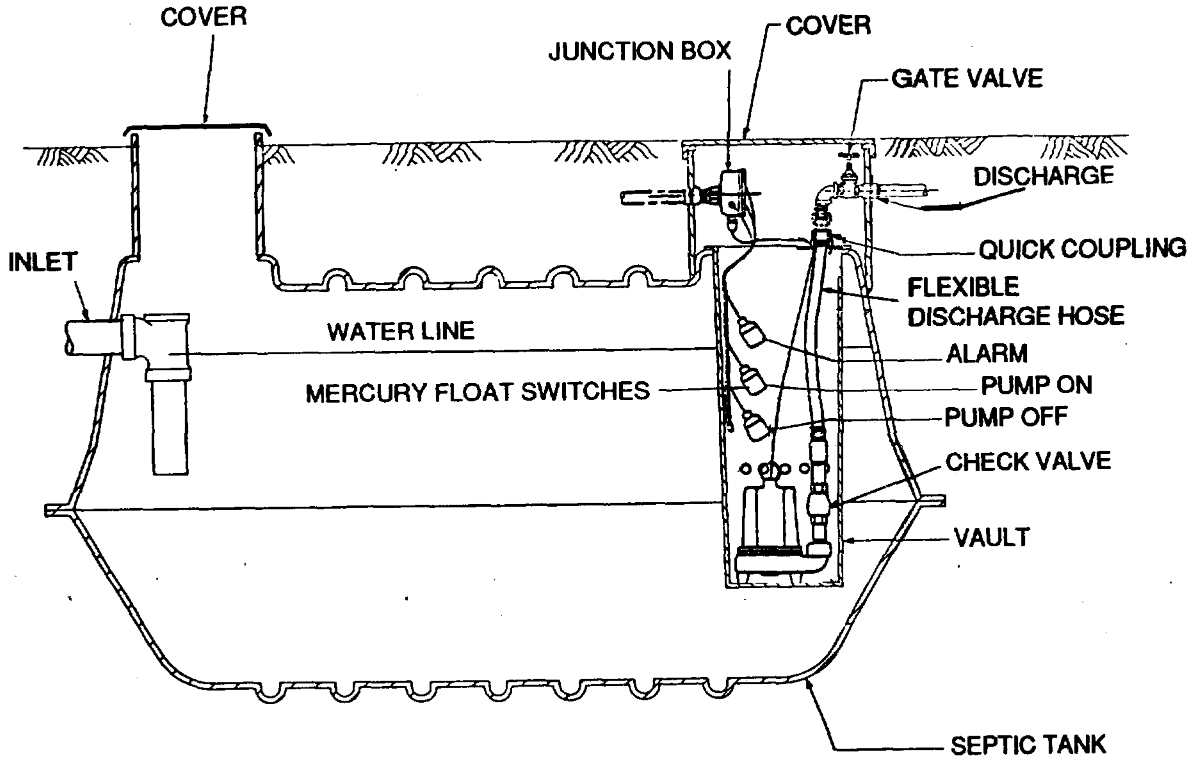


Figure 2-8. Typical STEP package with internal pump vault. (CourtesyBarnes Pump Co.)



A riser extends to ground surface, providing access to the pump vault. In some designs the pump vault is removable through the riser, for access to the tank. In other designs the pump vault and riser are integral in which case access to the tank is made through the cover on the inlet end of the tank which may be buried or may also have a riser extending to ground surface.

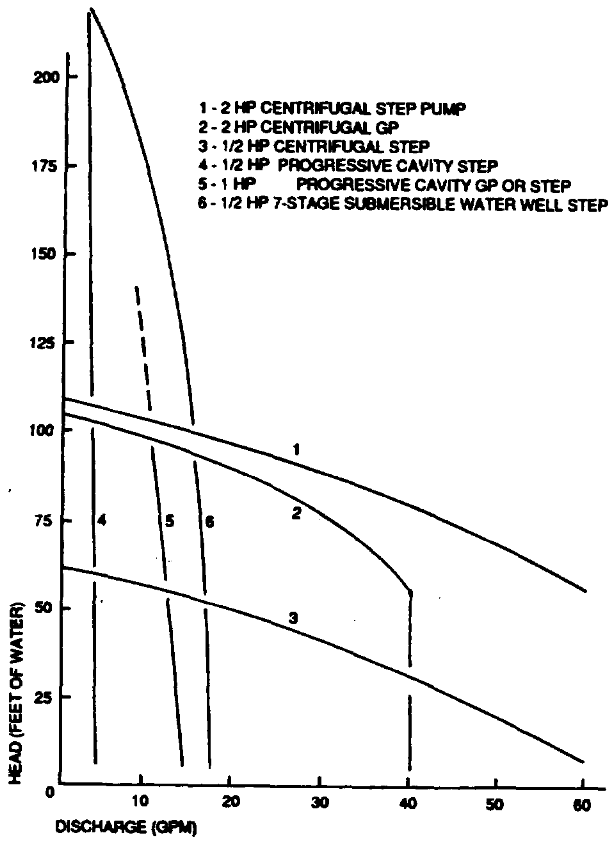
Inlet holes (ports) are provided in the pump vault as shown, which are located below the lowest predicted elevation of the scum in the tank during the lowest water level condition, but above the maximum height of the sludge layer.

The liquid level in the entire septic tank rises and falls in response to flows from the home and the pumping cycle. When the liquid level rises for example 7.5 cm (3 in) (about 50 gal), the pump turns on and pumps down the whole tank 7.5 cm (3 in). If a malfunction occurs and the liquid level rises sufficiently above the pump-on level, a high level alarm is activated. The reserve space is located between the top of the floating scum and the soffit of the tank.

The GP, SH, and STEP systems shown in the figures are available as simplex units, intended to serve one home, or perhaps up to 3 homes. Larger systems are also used, to serve many homes. The designs vary from duplex versions of the designs shown to full-scale wastewater lift stations. When large STEP installations are made, either large septic tanks are used, or several tanks are placed in series, with the final tank being the pump tank.

Pneumatic ejectors have been used to a limited extent on STEP systems, but none are now known to be marketed. Some STEP installations use submersible water well pumps, which must be used in conjunction with an inlet screen since well pumps have no solids handling capability. Well pumps also must be placed in a tube to simulate a well casing, to cause water entering the pump to flow past the motor, providing cooling. Progressive cavity pumps

Figure 2-9. **Head-discharge curves for typical GP and STEP systems.**



have been used some on STEP systems as well as on GP systems.

The pump characteristics vary with the manufacturers, but a general overview of the head - discharge curves is shown in Figure 2-9.

2.3.3 Materials of Construction

The use of proper tankage is particularly important. If a tank fails, the contractor must re-enter the homeowner's property with heavy equipment, excavate to remove the failed tank, and place the new tank. It is a most costly and visible mistake.

Pump vaults are most commonly made of FRP (fiberglass reinforced polyester). Those provided by the pump manufacturers are usually quality products, having a minimum wall thickness of about 6 mm (1/4 in). Some are gel coated which provides a smooth protective surface, and those that are not gel coated have resin rich surfaces intended to prevent glass fibers from being exposed that could cause wicking.

Some FRP vaults may be as thin as 1.5 mm (1/16 in) in places. The product may not be produced from quality materials or with quality workmanship, and fibers may be exposed. These are usually produced by other than the original pump manufacturer (aftermarket items).

Other pump vaults have been made of both high density and low density polyethylene (PE). PE is more flexible than FRP, so where the vaults are intended as a structural member, they must be thicker than FRP. PVC has also been used, usually made from sewer pipe.

Septic tanks on STEP systems have been made of reinforced concrete, FRP, and PE. Depending on the quality of the product, all of these materials have been successful, and in other cases all have been unsuccessful. In certain instances reinforced concrete tanks have cracked badly, admitting groundwater. FRP tanks have cracked or split open, in some cases have collapsed, and in other cases water seeped through the walls. Some PE tanks have deformed so badly as to not be functional and to demand replacement. In other instances they have collapsed totally.

Where the liquid level in the septic tank is lower than the groundwater, infiltration can occur if the tank is not water tight. There are numerous projects where I/I into the upstream sewer and septic tank has more than quadrupled flows, pushing the pressure sewer system beyond its capacity and rendering it a failure.

Judging structural integrity by observation of the tank being used as a part of an existing septic tank - soil absorption system has proven misleading. First, it is often impossible to know if a septic tank used with an absorption system leaks or not. Secondly, tanks which apparently do not leak in septic tank-soil absorption service may leak under pressure sewer service owing to potentially lower groundwater levels.

To evaluate the septic tank structurally, it is necessary to prepare a loading diagram depicting the loads the tank will be subjected to, commensurate with burial depth, groundwater depth, soil types, foundation, bedding and backfill to be used, and other parameters. Following this task the tank is designed by usual engineering analyses.

Generally, concrete tank designs follow American Concrete Institute standards, assuming one-way hinged slabs spanning the shorter dimension. Non-traffic load designs usually result in concrete tanks having an equivalent of 10-cm (4-in) walls and top and bottom slabs, with #5 bar reinforcement at about 20-cm (8-in) centers. A thickness of sacrificial concrete above the water line may be provided in anticipation of corrosion by H_2SO_4.

The thickness required of FRP tanks varies considerably with tank shape and the quality of the FRP product. When this has been evaluated, the usual conclusion has been to require an average wall thickness of 6 mm (1/4 in), with a minimum thickness at any point of 5 mm (3/16 in).

Because polyethylene is so flexible the shape of PE septic tanks is crucially important. Flexible tanks can deform to a shape of structural weakness if not properly designed. PE tank designs generally rely considerably on empirical refinement, taken from monitored experience on numerous installations under varying conditions.

Quality control of the tank manufacturing process must be assured. It has been common for tank construction to be poorly executed.

Septic tank effluent and the septic tank atmosphere are corrosive due to the hydrogen sulfide present above the water line and the potential for sulfuric acid formation. The wastewater in a grinder pump vault may also become septic due to the wastewater being sometimes held in the pump vault for extended periods. Exposed appurtenances must be suitably corrosion resistant.

In most cases where the pumping package has been supplied by a manufacturer with considerable pressure sewer experience, the engineer can be reasonably assured that acceptable materials have been used.

When component systems are built the engineer must pay strict attention to materials choices.

The materials chosen for corrosion resistance vary according to the material properties needed for structural and other reasons.

Austenitic stainless steel, particularly Type 316 and in some cases Type 304 have proven to give excellent service. Fasteners are produced from this material, also such items as hose clamps. Martensitic stainless steel, such as Type 416, has generally proved unacceptable.

Some plastics are virtually unaffected by exposure to H_2S while others are not. PVC, ABS, and PE, all materials that have long been used in sewerage service, appear acceptable. Nylon, however, is affected by H_2S and H_2SO_4, and is not acceptable.

Copper products, e.g., alloys of brass or bronze, provide limited success. Besides corrosion considerations brass is subject to dealloying, while some bronze, such as 85-5-5-5, will give better performance. The terms brass and bronze are used loosely despite having different meanings; the engineer is advised to evaluate these materials with caution.

2.4 System Design Considerations

2.4.1 Hydraulics

2.4.1.1 Design Flows and Their Variability

a. *Average Daily Flows*

Fundamental to the design of a sewer system is the determination of design flows. Where actual flow characterization data are available they should be used. An allowance of 380 L/cap/d (100 gpcd) has been used as a general rule in the design of conventional sewer systems.[8] However, that general rule may allow for more infiltration than may occur when pressure sewers are used, and it allows for some amount of commercial and industrial use that may not be present in pressure sewer design. Experience with pressure sewerage has shown a lower allowance to be more in order.

During the early stages of pressure sewer development extensive investigations were made into domestic water consumption during periods of low outside water use, with the correlation that water consumption would closely parallel sewer flows. These studies showed flows of 150-230 L/cap/d (40-60 gpcd). Flow measurements were made on conventional sewers serving residential communities during periods when I/I was not occurring, with the same conclusions.

At this time, thousands of flow measurements have been made on pressure sewer systems with wide demographic spread.[9] The result of these measurements has corroborated findings of the earlier studies; that flows are typically 150-230 L/cap/d (40-60 gpcd), with little weekly or seasonal variation.

The availability and quality of water affects water use and consequently sewer flows, as does water pressure, community affluence, nature of occupancy, and attitudes of the users regarding water conservation. Because of these variables and to provide a safety factor, the flow rate normally assumed for design is 190-265 L/cap/d (50-70 gpcd).

While pressure sewers are sometimes thought to be free of I/I, it can occur in the non-pressurized portions of the system, e.g., the building sewer and the tank. In some cases I/I has been extreme, due to leaking building sewers or house roof drains being connected to the building sewer, due to pump vault risers being set below ground level which allows surface water to enter, or in the case of STEP systems due to leaky septic tanks. It is prudent to make an allowance for I/I when adopting a design flow, based on the extent of I/I control given to the project.

Daily peak flows may exceed design values by several times and occur several times per day but these are of little importance due to their short duration. There are also periods of zero flow.

Flow variations are related to mainline sizing and pump selection. That is, an oversized system will tend to have more peaky flows than a system with smaller diameter mains, where the pumps run longer per cycle at lower discharge rates.

On the Glide, Oregon STEP system, peak hour flows were found to occur about twice/day, at flow rates of 40-65 percent of design peak flows. The Glide system at that time served 560 equivalent dwelling units (EDUs) and was sized to serve an ultimate population of 2,380 EDUs. The 32-km (20-mi) piping system is 7.5-30 cm (3-12 in) in diameter.

b. Peak Flows From Homes and Required Pumping Rates

Besides average daily flow rates and their variabilities it is important to consider other factors, such as the rate of flow from the individual home to the septic tank or GP vault. This flow rate can be quite high at times.

The American Society of Civil Engineers[2] reported peak flows that may occur about twice per year as being 98 L (26 gal) in a 4-min period, or 408 L (108 gal)/hr. They go on to describe the simultaneous discharge from a bathtub and clothes washer resulting in a 174-L (46-gal) discharge over a 2-min period, and having a high probability of occurrence.

Bennett[10] reported surge flows of 230 L (60 gal) in a 7-min period. Jones[11] reported findings similar to those of ASCE and Bennett and applied the data to regression analyses. The results of the various studies are shown on Figure 2-10.

If the purpose of the pressure sewer pump was to discharge flows as fast as they enter the tank, required pumping rates would be quite high to accommodate these instantaneous peak flows. However, the purpose of the pressure sewer pump is to discharge flows at a rate such that the level in the tank will not reach the high water alarm level, and with a high degree of confidence, will not overflow the basin. The reserve volume within the tank between pump on and high level alarm is used to attenuate peaks and is a factor in establishing required pumping rates.

Required pumping flow rates should not be confused with design flow rates used for sizing mains, as the latter does not consider attenuation of peak flows from the home provided by the volume held between pump on and alarm levels in the pump vault.

Figure 2-11 adopts the 1-percent regression of Reference 11 and Figure 2-10 and presents pumping rates required given four different volumes of reserve space. The curves on Figure 2-11 have been calculated based on the following equation:

$$Q = (V-S)/t \qquad \text{Equation 2-1}$$

Where,

Figure 2-10. **Wastewater flows for one home.**

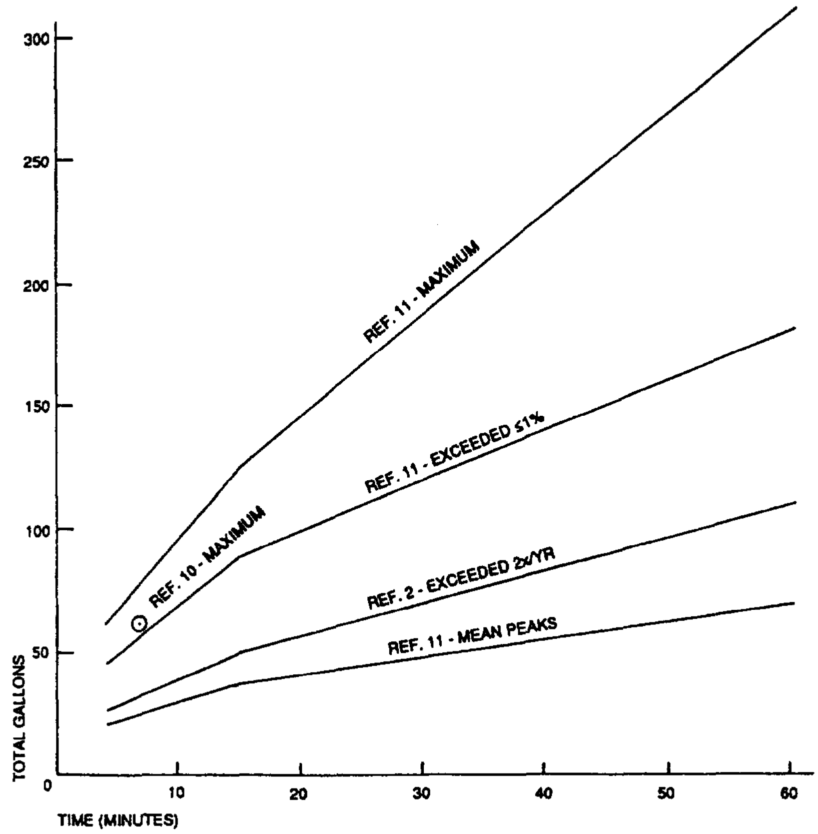
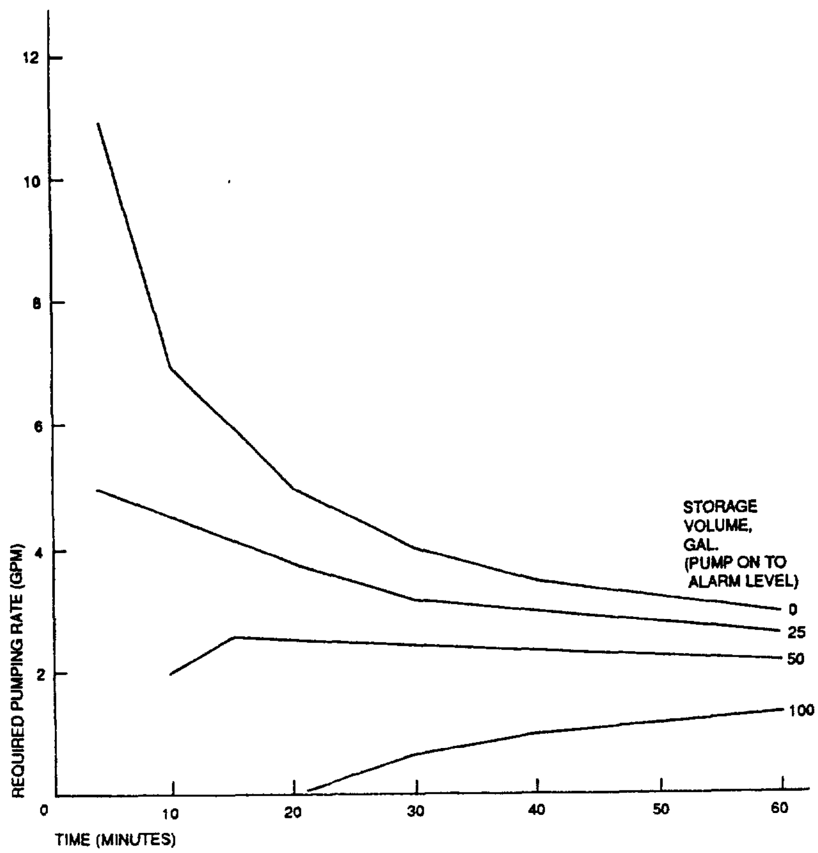


Figure 2-11. **Required pumping rates using flows from Reference 11, <1-percent regression.**



Q = Minimum required pump discharge rate (gpm)
V = Volume of peak wastewater flow from the home (gal)
S = Storage volume between pump on and alarm (gal)
t = Time (minutes)

Figure 2-11 shows, for example, a minimum required pumping rate of 10 L/min (2.6 gpm) if 132 L (50 gal) of reserve is provided. However, a higher pumping rate is not detrimental in most cases. When using a grinder pump system where pipeline cleansing velocities are required, a higher pumping rate may be needed for that purpose.

c. Design Flows

Design flows are maximum flow rates expected to occur once or twice per day, and are used to size the pressure sewer mains. Flow rates in excess of design flows can occur under certain situations to be described later, so design flows should not be taken as the maximum flow rate possible to occur.

Two design approaches have been used; the probability method and the rational method.

The probability method proposes the maximum number of pumps theoretically expected to be running at any time. Then, with the discharge rate of the pumps being known or assumed, the design flow is the product of the number of pumps running times the pump discharge rate.

Many pressure sewer pumps are centrifugal, having gradually sloping head-discharge curves, so the discharge rate varies considerably depending on the discharge pressure. Consequently the pumping rate in the probability method is only loosely assumed when centrifugal pumps are used. The probability method would best apply to pumps having vertical or near vertical head-discharge curves, such as semi-positive displacement pumps, e.g., progressing cavity types.

The rational method can logically be applied when either centrifugal pumps or semi-positive displacement pumps are used. The rational design has almost exclusively become the accepted method of practice.

The rational method proposes a design flow corresponding to the number of homes served by the pressure sewer, which is used to size the mains and to construct the design hydraulic grade line. Pumps are then selected that can discharge into the main at an acceptable flow rate given the design discharge pressure.

Environment One. The design handbook of Environment One Corporation, manufacturers of progressing cavity type grinder pumps and effluent pumps, tabulates the number of pumps expected to be running simultaneously versus the number of pump cores connected to the system.[12] Design flow rates as shown in Figure 2-12 are then determined by the product of 11 gpm (the discharge rate of their pump) times the number of pumps running.

Information from a study by ASCE[2] was used to derive the E-1 design flow rate curve which was then refined by operating experience with projects using their equipment.[3] The ability of their pumps to operate at least 25 percent above design pressure accommodates occasional peak flow needs in excess of design.

ASCE. A study by the ASCE[2] was accomplished early in the history of pressure sewer development, based on water supply demand rates in northern latitudes and during periods when outside water use was minimal.

Based on Johns Hopkins University data and referencing work by McPherson, tables of flow were prepared. Measurements of 15 systems in the northeastern United States were shown, serving 44-410 EDUs. In northern California, measurements were made of 13 systems serving 63-295 EDUs. Curves were drawn from these data expressing a ratio of maximum peak hour of any day to average annual use.

Hydromatic. Hydromatic pump company sponsored a study and report by Battelle Institute which explored the use of centrifugal grinder pumps.[13] A number of information sources were cited, including that from the Grandview Lake,[4] Indiana pressure sewer project, the Albany, New York study,[3] and work by Watson, Farrell, and Anderson.[14]

A specific equation for peaking factor was taken from Fair and Geyer's text,[15] citing Harmon's measurements of conventional wastewater flow:

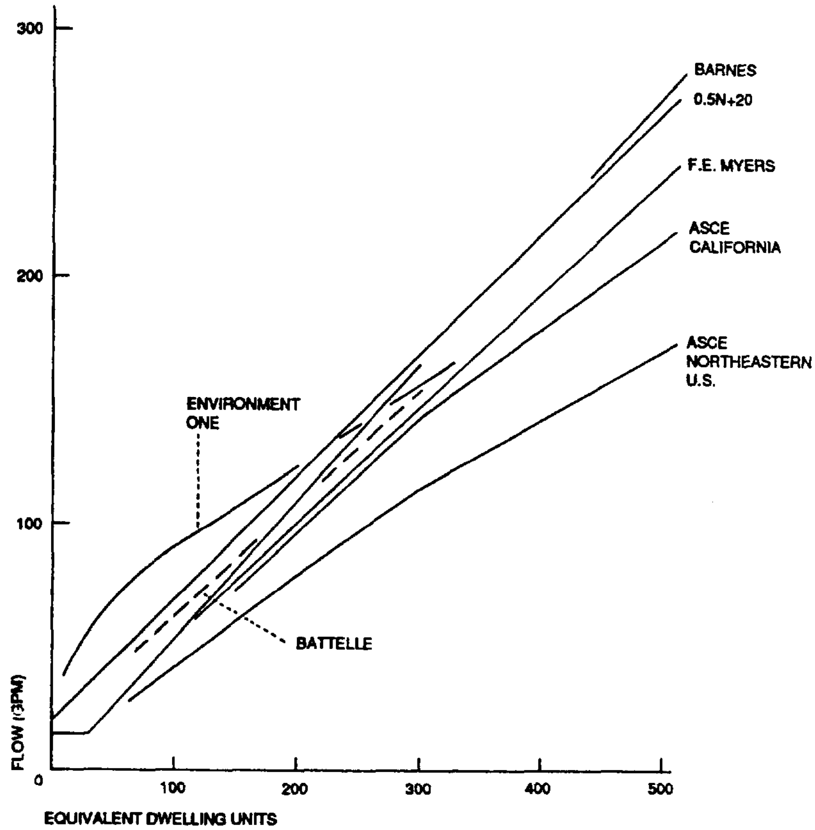
$$Q_p/Q_a = (18+P)^{0.5}/(4+P)^{0.5} \qquad \text{Equation 2-2}$$

Where,

Q_p = Peak flow
Q_a = Average flow
P = Population in thousands

Eight tables were presented ranging from flows of 660-1,515 L/s (175-400 gpd)/EDU. Although not stated within the report, Equation 2-2 fits the data in Battelle's tables exactly, excepting for low flows where departure was apparently regarded as necessary owing to the differing nature of pressure sewer collection as contrasted against

Figure 2-12. **Design flows.**



gravity sewer collection. A design flow of 1 L/s (15 gpm) was suggested for one home, and 1.6 L/s (25 gpm) for 5 homes.

Flows shown in the tables are reported to be recurring peak flows, to occur once or twice per day.

The table corresponding to average flows of 740 L/s (195 gpd), and occupancy of 3.5 people/EDU has been used most frequently in pressure sewer design, and was used for the curve shown in Figure 2-12.

Battelle's tables have been widely used for both GP and STEP designs.

Barnes. The design manual provided by this manufacturer of centrifugal grinder pumps and effluent pumps proposes a peaking factor of 3, and assumes that flows occur over an 18-hr period, which results in a peaking factor of 4 over a 24-hr period.[16] Their equation is re-expressed as Equation 2-3. A minimum flow of 1 L/s (15 gpm) is suggested. The Barnes recommended design curve as presented in Figure 2-12 assumed an average flow of 760 L/s (200 gpd)/EDU.

$$Q_p = 4\,Q_a \qquad \text{Equation 2-3}$$

F.E. Myers. This pump manufacturer's design handbook provides a plot of peaking factor versus the number of dwellings served, with the peaking factor varying from 4.8 at zero EDU to 3.4 at 700 EDUs.[17] They suggest an average daily flow expected when serving 3-bedroom homes of 950-1,510 L/s (250-400 gpd).

Simplified Equation. By examination of the curves shown in Figure 2-12, a simplified equation has been fitted. The reasoning in proposing a simplified equation is that a precise determination of flows is not possible to achieve anyway, especially with regard to infiltration allowance. The simplified equation is easy to use and easy to modify to suit project needs.

$$Q = AN + B \qquad \text{Equation 2-4}$$

Where,

Q = Design flow (gpm)
A = A coefficient selected by the engineer, typically 0.5
N = Number of EDUs
B = A factor selected by the engineer, typically 20

In the usual form, the equation is Q = 0.5N + 20, but may be varied to account for anticipated high water use (and correspondingly high wastewater flows), to allow for a greater safety factor, and especially to allow for I/I. Varying the coefficient A steepens or flattens the curve while varying the factor B raises or lowers the curve.

The design curves proposed by the various manufacturers have been widely used. In the vast majority of cases the systems have performed well, indicating that the design curves are adequate. However, many systems have been sized for growth that has not yet occurred, so these systems have not yet been fully tested. Most systems are not equipped with flow meters that would measure peak flows, nor are pressure readings routinely taken, so acceptable performance is only judged by the lack of nuisance high water alarms during peak periods.

Systems that have proven inadequate typically received I/I far in excess of that anticipated.

2.4.1.2 Minimum Flow Velocities in Pipes

The term "self cleaning velocity" refers to the flow velocity required to convey solids along with the water carrier. To maintain an unobstructed pipeline, that velocity should be sufficient to transport grit that may be present in the wastewater, to prevent grease plating on the crown of the pipe, and to scour and resuspend previously settled matter.

When force mains are used to convey conventional wastewater or when a grinder pump pressure sewer is used, the typically ascribed self cleaning velocity is usually taken as about 60-90 cm/s (2-3 fps). That velocity should occur once or twice daily. The higher velocity of 90 cm/s (3 fps) is preferred with regard to scouring concerns, but the higher flow rates correspond with higher headlosses and the need for higher head pumps.

The septic tank of a STEP system is effective at capture of grit and grease. It is logical that the required self cleaning velocity would be much reduced when septic tank effluent is pumped. Assuming values of $s = 1.1$ and $D_g = 0.2$ mm for septic tank effluent, and applying Camp's equation for sediment transport,[18] results in a self-cleaning velocity of less than 30 cm/s (1 fps).

Experience has shown that if GP flow velocities are too low grease collects at the crown of the pipe, restricting the cross sectional area and interfering with the transfer of air to air release valves, and increasing headlosses against which the GPs must pump.[3] Grit can also collect at the invert of the pipe.

There have been occasional reported instances where velocities on small portions of GP systems have been so low that pipeline clogging has occurred, necessitating pipeline cleaning.

Experience with STEP systems has shown that solids are not deposited even when velocities are less than 30 cm/s (1 fps). However, a self-cleaning velocity of 30 cm/s (1 fps) may be conservatively used.

With either GP or STEP systems, sand and other debris can enter the pipeline during construction which can become cemented due to contact with the septic wastewater, and difficult to remove. The pipeline should be kept capped at all times during construction except when pipe laying is being actively accomplished, and other measures taken to insure that the pipe is kept clean.

Mains should be designed to withstand the forces of pipeline cleaning by pigging, should that become necessary. The more common need for pigging is to remove debris that entered the pipe during construction. Pig launching stations have been provided on a few projects, but usually they are regarded as an unnecessary expense and encumbrance.

Pressure monitoring stations have occasionally been used on large projects. The methodical and routine taking of pressure readings can help reveal progressive pipeline clogging, but more often it shows effects of air binding.

2.4.1.3 Applicable Equations

The Hazen-Williams Equation is most often used to forecast headloss, but the Manning Equation is acceptable. When the Hazen-Williams Equation is used the C factor is selected by the engineer, typically being 130-140 for plastic pipe. A corresponding Manning n value is 0.010.

Hazen-Williams:

$$V = 1.318C\,R^{0.63}S^{0.54} \qquad \text{Equation 2-5}$$

Manning:

$$V = 1.486/n\,R^{2/3}S^{1/2} \qquad \text{Equation 2-6}$$

Where,

V = Velocity of flow (fps)
C = Hazen-Williams flow coefficient
R = Hydraulic radius
S = Slope of energy gradient
n = Manning flow coefficient

Where pipelines flow partly full, as in some gravity reaches within a combined pressure sewer-small diameter gravity sewer, the velocity can be easily calculated by the Pomeroy Equation:

$$V = 6.8\ S^{0.41}Q^{0.24} \qquad \text{Equation 2-7}$$

Where,

V = Velocity of flow (fps)
S = Slope of energy gradient
Q = Flow rate (gpm)

2.4.2 *Pipelines*

2.4.2.1 Mainlines

a. Geometry
The geometry of a pressure sewer system is similar to that of a water distribution system, but normally in dendriform pattern, as opposed to a network in which the pipelines are looped. The purpose of the branched layout is to have a predictable minimum self-cleaning velocity in the mains, but a disadvantage is that redundancy is not provided as it is in a looped system. With a network, a section of the piping system can be shut down for repairs without interrupting flow from all upstream inputs, as flow from them is naturally redirected.

In some pressure sewer designs a network pattern is used with mainline isolation valves in the normally closed (NC) position. These isolation valves are located such that the system operates the same as a dendriform layout would, excepting during a period when a portion of the main is shut down for repairs, in which case the normally closed valve is temporarily opened and flows are redirected. The practice of network layout using NC valves is more common with STEP system design than with GP systems owing to their reduced need for cleansing velocities.

Pressure sewer geometry also differs from most water supply systems in that some reaches of the pressure sewer may flow part full (by gravity). In profile, pressure sewer systems are sometimes arranged to pump only upslope, or to confine downslope piping to steep and distinct reaches where hydraulic conditions are more predictable.

b. Pipe Sizing
For rough planning purposes the Equation 2-8 may be used, and a velocity of flow assumed at 60 cm/s (2 fps). Table 2-1 shows the resulting number of homes that could be served by various mainline sizes.

Table 2-1. Approximate Main Sizes Required to Serve Number of Homes Shown (Using Q = 0.5 N + 20, and V = 2 fps)

Pipe diameter (in)	No. Homes Served
2	6
3	60
4	120
6	240
8	560

$$Q = 0.5N + 20 \qquad \text{Equation 2-8}$$

Where,

Q = Design flow, gpm
N = Number of homes served

There is little economy in using 5-cm (2-in) mains. 7.5-cm (3-in) pipes can be installed in the same trench, with the same backfill, labor, and engineering, yet the 7.5-cm (3-in) main has considerably more capacity. Also, saddle-type, "wet-tap" 32-mm (1-1/4 in) service line connections can be made to the 7.5-cm (3-in) main, but 32-mm (1.25-in) wet taps cannot be made to the 5-cm (2-in) main. 7.5-cm (3-in) pipe is readily available in gasketed joint, but 5-cm (2-in) is commonly available only in solvent weld joint. For these reasons 7.5-cm (3-in) is becoming the smallest preferred main size. An exception to this practice is when 5-cm (2-in) pipe is needed to maintain cleansing velocities.

c. Routing
In most cases pressure sewer mains are located outside of and adjacent to the edge of pavement and approximately parallel to the road or street, which reduces the expense of pavement repair and traffic control. In areas subject to unusual erosion, the preferred location is often within the paved area. This location is also favored by some municipalities as being an area where subsequent excavation is less likely and more controlled, and therefore being a location more protected from damage.

An advantage to the use of pressure sewers is that the small diameter plastic pipe used is somewhat flexible and can be routed around obstacles. This feature allows pressure sewers to follow a winding path as necessary. The pipe should be bent in a long radius if possible, not in a radius less than that recommended by the pipe manufacturer. The minimum radius recommended by the Uni-Bell Handbook of PVC Pipe[19] for classes of pipe most used as pressure sewer main is given by Equation 2-9. In diameters larger than about 10 cm (4 in), the pipe is stiff and the practicality of achieving the allowed radius must be considered.

$$R_b/OD = 200 \qquad \text{Equation 2-9}$$

Where,

R_b = Minimum radius of the bending circle.
OD = Outside diameter of the pipe.

Pressure sewer mains are normally buried with a cover of about 75 cm (30 in). In a few cases where economy is paramount and subsequent damage is unlikely, they are buried more shallowly. In colder climates the depth of bury may be dictated by frost penetration depths. In the northern U.S. they are often placed at 1.2-1.5 m (4-5 ft), and in arctic conditions as deep as 2.4 m (8 ft) or deeper. In cases where these depths result in excessive capital/installation costs, alternative pipe materials which incorporate insulation and even heat tracing have been successfully employed.[20]

When using large diameter mains, the height of the isolation valves may dictate a minimum burial depth so the valve operator is sufficiently below ground surface. The height of air release valves can also dictate burial depth if the valves are to be fully underground.

The separation of pressure sewers from water supply mains and laterals often requires that the pressure sewer be buried deeper than would be required for other reasons. In most instances the separation requirements between the sewer and private wells and streams are dictated by state health departments, and the requirements differ throughout the United States. Typical requirements are shown in Table 2-2.

Profiles of mains are recommended and usually, but not always, shown on the plans. They may be omitted if the mains are only a few hundred feet long, if air release stations are not needed, and if there are no obstacles to be crossed.

Culvert and utility crossings often dictate numerous variations in the burial depth of pressure sewer mains, with many resulting sags and summits in the pipeline profile. In some cases these variations in the profile are hydraulically detrimental regarding the accumulation of air at the summits. When the variations are regarded as detrimental, reaches of the pressure sewer main may be placed at a particular depth to allow for the crossings, or otherwise profiled to minimize summits.

To minimize damage to the pressure sewer main caused by subsequent excavation, ground surface route markers are sometimes placed adjacent to or above the main, warning excavators of its presence. Good as-constructed plans are helpful in identifying the pipeline location, and a cable buried with the main can be induced with a tone so the main can be field located using common utility locating equipment.

Table 2-2. **Typical Requirements for Separation of Pressure Sewer Lines From Water Lines[21]**

Parameter	Requirement
Parallel Installations	Locate sewer as far as practical from water main. Minimum separation 3 m (10 ft). If sewer is closer than 3 m (10 ft) from water main, sewer is to be located 30 cm (12 in) lower than the water main. In some jurisdictions, when closer than 3 m (10 ft), sewer is to be of water main materials or encased. Other jurisdictions allow water and sewer in the same trench if the sewer is 30 cm (12 in) lower.
Crossings	Crossing is to be as nearly perpendicular as practical. Sewer to be 30 cm (12 in) lower than water main. Some jurisdictions require that no joints be used in the sewer main within 3 m (10 ft) of the crossing.

A warning tape marked "pressure sewer" is sometimes placed shallowly in the pipeline trench to further notify excavators. When the tape is placed lower in the trench, e.g. adjacent to the pipe, it is called an "identification" tape. The tape can be metalized so it can be detected with utility locating devices, but most tape cannot be induced with a tone, so metalized tape should be placed shallowly to be detected.

d. Trench Section

Trenching may be accomplished using a backhoe, wheel trencher, or chain-type trencher. The choice of equipment is usually dictated by the contractor based on equipment availability and the material to be excavated.

Imported material termed "pipe zone backfill" is often placed to surround the main several inches if material excavated from the trench is regarded as unsuitable for use as that material. Pipe zone backfill is usually granular, as pea gravel or coarse sand. Fine sand or soil is generally not as desirable as it bulks rather than flowing into place densely under the pipe haunches.

The remaining backfill material required is often specified by the agency controlling the road or street, especially if the mains are located within the pavement.

In some cases a lean cement-sand slurry is used for backfill. This option is particularly attractive when a narrow trench is used, the mains are located within the pavement, and prompt restoration for traffic is important.

e. Pipe Materials

PVC is most widely used. Polyethylene has also been used, especially when the number of joints must be minimized, or when it is selected for visual identification in contrast to PVC water mains. Polyethylene has also been used for lake crossings, and in insulated and heat-traced form for arctic installations.

The commonest PVC mains are iron pipe size (IPS) 1,400 kPa (200 psi) working pressure rated, standard dimension ratio (SDR) 21, or 1,100 kPa (160 psi), SDR 26. Even though the operating pressures in the mains may be far lower than the working pressure rating of the pipe, lower rated pipe is not normally recommended. Thinner wall pipe is more likely to be seriously damaged during installation. Also, the mains should be built to withstand the pressure of hydraulic cleaning using a pipe cleaning pig. SDR 26 pipe has been reported to suffer damage when used with high-head pumping units.[4] In some cases SDR 26 is used only in sizes 10 cm (4 in) and larger, to avoid the thin wall characteristic of smaller pipes.

On small diameter gravity sewer projects, PVC sewer pipe, ASTM D-3033 or D-3034 is often used. This pipe has a different outside diameter than IPS, and in some sizes, the outside diameter of D-3033 is different from that of D-3034, so the availability of fittings should be investigated.

When PVC mains larger than about 20 cm (8 in) are used, AWWA C-900 pipe is sometimes specified, often for reasons of the availability of proper fittings. This pipe is available in two types, iron pipe size, and cast iron pipe size, the latter being a different outside diameter than either IPS or sewer pipe.

Pressure irrigation pipe (PIP) is often used to fabricate pump vaults and other appurtenances, and has a different outside diameter than any of the other pipes mentioned.

See Table 2-3 for an abbreviated listing of pipe dimensions.

Refer to the Unibell Handbook of PVC Pipe[19] for a more thorough listing. Checking with manufacturers for availability is required as many companies do not produce all the pipes said to be available.

PVC pipe has a high coefficient of thermal expansion; about 3/8-in of length variation/100 ft of pipe/10°F temperature change.

$$\text{Coefficient} = 3.0 \times 10^{-5} \text{ in/in/°F} \qquad \text{Equation 2-10}$$

Considerable temperature changes will be experienced during pipeline installation, and some degree of temperature change will occur during operation, with climate changes and effluent temperature changes. To reduce expansion and contraction induced stresses, flexible elastomeric ("rubber ring") joint pipe is preferred for use as mains.

If solvent weld joint pipe is used, the pipe manufacturer's recommendations for installation regarding temperature considerations should be followed. The Uni-Bell Handbook of PVC Pipe[19] also provides guidance as to proper practices.

Fittings most often used are of the solvent-weld joint type. They are more commonly available than gasketed joint fittings, and expansion and contraction are allowed for in the remaining pipe joints. Care must be taken for proper solvent welding, especially when using larger pipe sizes that are difficult to handle.

f. Appurtenances

Isolation valves (IVs) are used on pressure sewer mains much as they are on water mains. Gate valves may be used, or resilient-seated gate valves, and occasionally ball valves are used. Typical locations for IVs are at intersections, both sides of bridge crossings, both sides of areas of unstable soil, and at periodic intervals on long routes. The intervals vary with the judgment of the engineer, but are typically about 0.8-1.6 km (0.5-1 mi).

Cleanouts are occasionally provided. The most common type consists of a valved wye extending to ground surface that can launch a pipe cleaning pig. When cleanouts are provided, they are typically placed at the ends of mains, and where main diameter sizes change.

Thrust anchors should be used as they are in water main practice. Even though the operating pressure in the main may be low enough that thrust anchors may not seem to be required, the main should be hydrostatically tested following installation at a pressure of about 1,400 kPa (200 psi). A properly installed PVC pipeline will easily pass that pressure test, but a poor installation will be revealed. Thrust anchors and a quality installation may also be required if pipeline cleaning by pigging is anticipated.

Table 2-3. Abbreviated Listing of PVC Pipe Dimensions

IRON PIPE SIZE (IPS)

Nom. (in)	O.D.	Min. wall SDR-26 CL. 160	Min. wall SDR-21 CL. 200	Sch. 40	Sch. 80
1/2	0.840			0.109	0.147
3/4	1.050			0.113	0.154
1	1.315			0.133	0.179
1-1/4	1.660			0.140	0.191
1-1/2	1.900		0.090	0.145	0.200
2	2.375		0.113	0.154	0.218
2-1/2	2.875		0.137		
3	3.500		0.167		
4	4.500	0.173	0.214		
6	6.625	0.255	0.316		
8	8.625	0.332	0.410		
10	10.750	0.413	0.511		
12	12.750	0.490	0.606		

Note: Other thicknesses include SDR-13.5, SDR-32.5, and SDR-41.

SEWER PIPE PSP ASTM D-3033

Nom. (in)	O.D.	Min. wall SDR-41	Min. wall SDR-35
4*	4.215	0.125	0.125
6	6.275	0.153	0.180
8	8.160	0.199	0.233
10	10.200	0.249	0.291
12	12.240	0.299	0.350
15	15.300	0.375	0.437

* 4" is SDR 33.5

SEWER PIPE PSM ASTM D-3034

Nom. (in)	O.D.	Min. wall DR-42	Min. wall DR-35
4*	4.215	-	0.125
6	6.275	-	0.180
8	8.400	0.200	0.240
10	10.500	0.250	0.300
12	12.500	0.300	0.360
18	18.700	-	0.536

AWWA C-900 CAST IRON PIPE SIZE (CIPC)

Nom. (in)	O.D.	Min. wall DR-25 PC.100	Min. wall DR-18 PC.150	Min. wall DR-14 PC.200
4	4.800	0.192	0.267	0.343
6	6.900	0.276	0.383	0.493
8	9.050	0.362	0.503	0.646
10	11.100	0.444	0.617	0.793
12	13..200	0.528	0.733	0.943

Table 2-3. Abbreviated Listing of PVC Pipe Dimensions (continued)

AWWA C-900 IRON PIPE SIZE

Nom. (in)	O.D.	Min. wall DR-25 PC.100	Min. wall DR-18 PC.150	Min. wall DR-14 PC.200
4	4.500	0.180	0.250	0.321
6	6.625	0.265	0.368	0.473
8	8.625	0.345	0.479	0.616
10	10.750	0.430	0.597	0.768
12	12.750	0.510	0.708	0.911

PIP IRRIGATION PIPE

Nom. (in)	O.D.	Min. wall SDR-100 50' Hd.	Min. wall SDR-32.5 125 psi
4	4.13	0.065	0.127
6	6.14	0.070	0.189
8	8.16	0.080	0.251
10	10.20	0.100	0.314
12	12.24	0.120	0.377
15	15.30	0.150	0.471
18	18.36	0.180	-
20	20.40	0.200	-

Note: Other thicknesses include SDR-41, SDR-51, and SDR-93.

Air release valves are required on major systems and require hydraulic analysis for placement. Water-system-type air release valves have been tried, mostly without success due to corrosion or clogging with sludge. Wastewater-type air release valves are recommended.

On pressure sewer systems serving more than about 500 homes, the provision of pressure monitoring stations (PMS) is advised. These consist of a small diameter service line connected to the side of the main, and extending to a terminus in a valve box or vault. An isolation valve is provided at the terminus, and a fitting necessary for connection to a mobile pressure sensor - recorder that may be moved from station to station. PMS are used to occasionally record pipeline pressures (the hydraulic gradient), to measure how the piping system is performing. This is particularly of interest over time, or it may be of interest if the placement or performance of air release assemblies are in question.

Flow meters are of considerable value, especially on large systems. Magnetic-type flow meters are the most common.

2.4.2.2 Service Lines

a. Geometry

Pressure sewer service lines are typically arranged similar to water services. A typical location is near and parallel to property lines, but where property line locations are not well known, it is advisable to maintain some distance from them.

It is good practice to field mark the location of the service line with boldly identified lath a few days prior to installation. This serves as a reminder to the property owner about the intended location and may cause the owner to recognize some reason that the location should be changed. It also serves as an advance notice to neighbors if property boundaries are in dispute.

Most municipalities prefer locating the service line where it will not be driven over, but other jurisdictions prefer locating the service line within the paved driveway. The reasoning is that subsequent excavation and associated damage to the service line may be less likely within the pavement.

Service lines should be located distant from potable water lines to reduce possibility of cross contamination. They should also be distant from other buried utilities if possible, due to the possibility of damage caused by the subsequent excavations for maintenance or repair of those utilities.

Service line profiles may normally undulate without much concern. The velocity and duration of flow and the typical diameter and length of service lines are such that air rarely collects in the summits to such an extent as to cause hydraulic problems.

b. Pipe Sizing

Typical service lines serving individual homes are 32 mm (1.25 in) in diameter, but have varied from 19 to 38 mm (0.75-1.5 in). A primary reason for what might seem to be over sizing is to limit headloss, so head-limited pumps can discharge at an adequate rate. A second reason for the seemingly large 32-mm (1.25-in) diameter is that check valves in that size will easily pass any solids that the pump can discharge.

Multiple EDU (MEDU) service lines are often 5-cm (2-in) diameter or larger and should be separately evaluated for hydraulic capacity.

To evaluate service line sizing, ordinates are subtracted from the pump curve for various discharge rates corresponding to headlosses in the service line. The resulting plot is the effective pump curve, that is, the characteristics of the pump at the main.

c. Trench Section

Where soil types allow the use of chain-type trenchers, use of trenchers is sometimes specified for service line installations as they cause less disruption to the property owners yard than backhoes. Rocky soils and some clayey soils that will not self-clean from the trencher teeth may be impractical to excavate using a trencher.

Street crossings are often accomplished by pushing a steel conduit under the street to act as a sleeve for the service line that is installed inside. Other street crossings are bored, or use a "hog." Open cutting of the street is done where other means are impractical.

Service lines are buried below the frost penetration depth, and usually at a minimum of 45-60 cm (18-24 in), as a measure of protection from subsequent excavations. In rocky settings in moderate climates, service lines are sometimes buried only 30 cm (12 in).

Bedding and backfill materials for service lines are usually the native material taken from the trench excavation, especially when a trencher is used and the material is well broken up. When the service lines are installed under travelled ways or when rock excavation is encountered, surrounding the service line with imported pipe zone backfill is advised.

d. Pipe Materials

Schedule 40 PVC is the most commonly used service line material. In small sizes, such as the normal 32-mm (1.25-in), conventional 1,100-kPa (160-psi), PVC pipe has a thin wall that is subject to damage during construction. It is for this reason that the heavier walled schedule 40 pipe is normally used, while lower-pressure-rated pipe is used for the larger diameter mains.

PVC service lines usually use solvent-weld-type fittings. Rubber ring fittings are not commonly available in small diameters. Also, service lines are short as compared to mains so thermal expansion and contraction is a lesser concern. The manufacturers instructions should be followed regarding pipe laying where substantial temperature changes are expected. Expansion joints are available as a separate fitting, intended for use on solvent-weld-joint pipe.

Polybutylene and polyethylene have also been used. Either of these materials can be installed without joints and are favored to place within conduits at street crossings. Compression fittings are used in preference to insert fittings which reduce the size of the opening in the pipe.

The service line should be pressure-tested. A common practice is to hydrostatically test the line while visually examining all joints prior to backfilling.

e. Appurtenances
Connections to the main can be made by tee or by service saddle. Tees can only be used when they are installed while the main is being placed. Service saddles can be used to make wet taps to the main in service. To place tees, the service line location must be accurately and reliably known at the time the main is installed.

Intuitively, wyes are sometimes thought to be preferable to tees, for connection of the service line to the main. However, wyes are not hydraulically superior. Neither are wyes available in pressure rated PVC. There has been limited use of non-pressure rated drain, waste, and vent (DWV) wye fittings, but they are available only in limited sizes, and their use is seldom seen.

Connections to the main should be of high quality, considering the large number of them, considering that they are buried, and that a small error can be compounded to be a large problem.

A corporation stop is typically used at the service saddle, and a gate valve or ball valve also used for isolation, sometimes placed at the street right of way line. A buried, redundant check valve is also often used on service lines. So the check valve can be later found, it is placed adjacent to the isolation valve which has a valve box riser to ground surface.

Alternately, the check valve and isolation valve are placed in a valve box. The valve box is usually too small to allow field personnel to remove and reinstall a valve, so the box has to be dug up to provide access. The box allows operation of the isolation valve handle, and marks the location of the facilities. When a valve box is used, consideration should be given to frost protection.

A toning wire or metalized marker tape buried with the service line facilitates future location.

2.4.2.3 Building Sewers

The term building sewer refers to the gravity flow pipe extending from the home to the interceptor tank or pump vault. In many cases state or local authorities regulate installations of building sewers. The Uniform Plumbing Code is often referenced.[21]

The building sewer should slope continuously downward as specified by state code, usually at a slope of not less than 0.25 in/ft, or 2 percent grade. Desirably, the pumping unit should be located near the home so the building sewer is short, with less need for maintenance and less opportunity for I/I.

If an existing building sewer does not have a cleanout, one should be placed outside and close to the home. Some agencies prefer having a cleanout at the dividing line where agency maintenance begins. For example, if a sewer district had placed 6 m (20 ft) of new building sewer to join an existing building sewer and if that point marked where district maintenance begins, a cleanout may be used there.

When GP or SH systems are used and the building sewer enters the pump vault without a tee or ell, maintenance of the building sewer may be accessed via the pipe end. However, some agencies prefer discouraging the pipe cleaning contractors from entering the pump vault.

Bends in building sewers should be avoided where possible, and a cleanout used for each aggregate change in direction exceeding 57°.[21]

Infiltration via leaking building sewers has been common, as has the connection of roof or yard drains. A quality installation is advised, which determines the existence of these and eliminates them during construction. Smoke testing has been effectively used to reveal sources of extraneous water, but care must be taken to keep the smoke from entering homes.

PVC or ABS piping materials are most widely used. Some regulatory agencies require ABS in certain locations, such as in proximity to the home, or under driveways where external loads may be high.

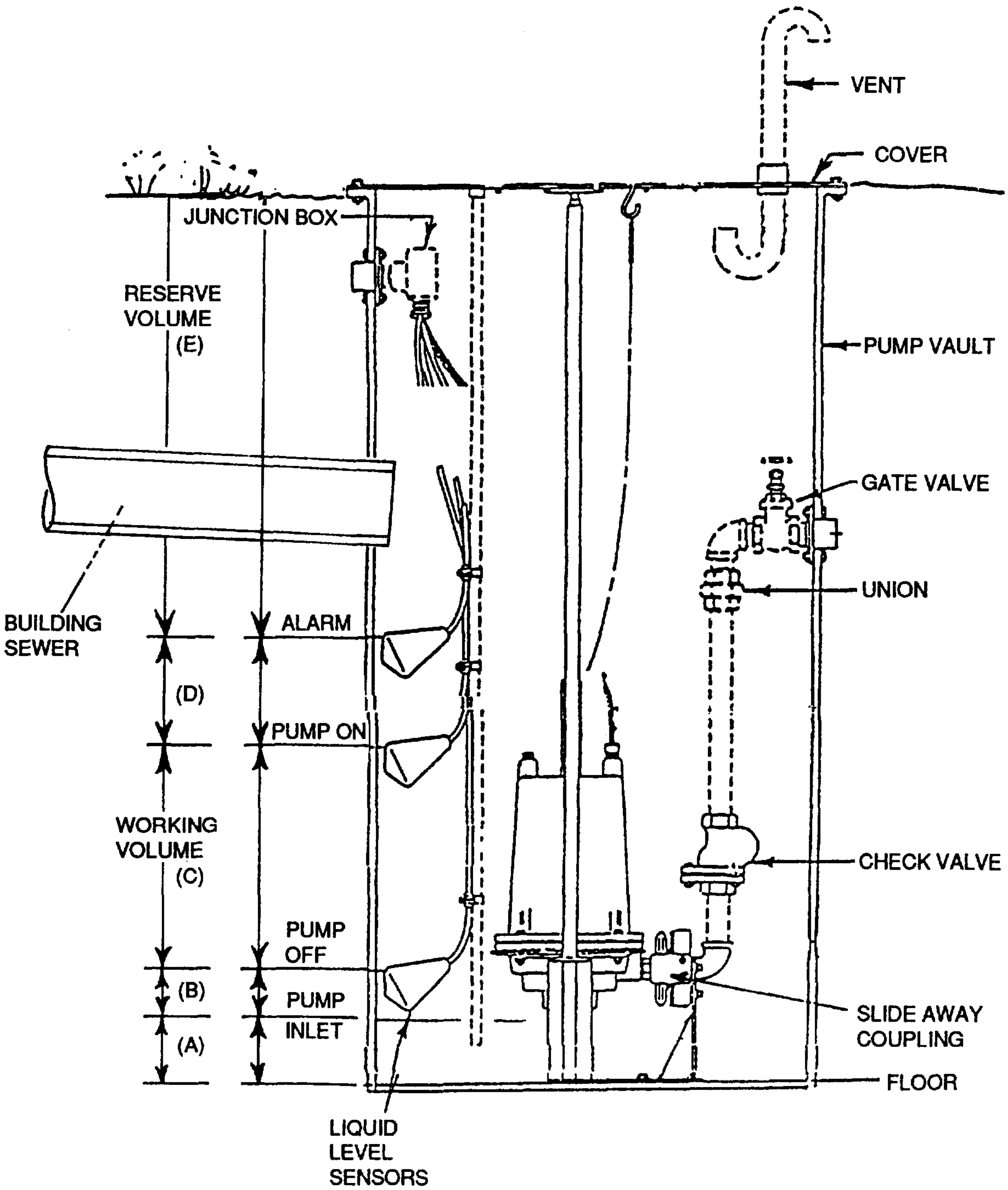
Direct burial (UF) or conduited wiring from the home to the pumping unit is often placed in the same trench with the building sewer, but this practice may require approval of the regulating authorities.

2.4.3.1 Grinder Pump and Solids Handling Pump Vaults

The various manufacturers of pressure sewer equipment provide somewhat different packages, but many generally resemble that shown in Figure 2-13. These vaults are typically made of FRP and vary in diameter from 60 cm to 120 cm (24-48 in), with the larger sizes usually being applied to duplex installations involving two pumps to serve a group of homes. The height may vary from 1.2 m to 2.4 m (4-8 ft).

The pump vault may be divided into zones, with each zone describing a particular purpose. Each manufacturer may have recommended dimensions to fit their own equipment, but to gain an understanding of the functions, an example is given. For ease in mental calculation of volumes held in circular basins, Equation 2-11 is used:

Figure 2-13. Zoning of GP or solids handling pump vault.



$$V = 6\ D^2 \text{ (approximate)} \qquad \text{Equation 2-11}$$

Where,

V = Volume per foot of depth (gal)
D = Inside diameter of basin (ft)

Referring to Figure 2-13, the pump inlet is seen to be suspended some distance (a) above the floor of the vault. This dimension may typically be about 10 cm (4 in).

The pump inlet is submerged some distance (b) below the lowest operating liquid level in the vault, the pump "off" level. This dimension may be about 2.5 cm (3 in), or a greater distance may be preferred to prevent vortexing. When using grinder pumps this dimension b is kept small so floating grease will not accumulate excessively.

The pump "on" level may be 30 cm (12 in) or so (c) above pump "off." If a 60-cm (2-ft) diameter basin is used, the working volume would be 91 L (24 gal) pumped/cycle (ignoring the volume displaced by the pump, and the wastewater entering the vault during the pumping cycle).

The alarm level is above the pump on level by some amount (d). In this example assume 15 cm (6 in) so the volume held in the basin between on and alarm is 45 L (12 gal), a small allowance.

If a duplex installation is used, the lag pump would turn on at the level shown as alarm in Figure 2-13, and the alarm level would be correspondingly higher.

Once the liquid level rises above the crown of the incoming building sewer, ventilation via the roof vent of the home is interrupted. Some users of GP or SH systems install a small P-trap vent through the cover or upper wall of the vault for continued ventilation under this condition.

Between the alarm level and the top of the basin is the reserve volume (e), if ventilation has been provided. Alternatively, an overflow may be provided to a holding tank or other structure (not shown).

The vault cover may be bolted on or, with some designs, the cover will be lifted up to allow a spillage on the lawn in preference to having backflow into the home in the unlikely event both the pump and check valves fail. If sized large enough, the P-trap vent accomplishes the same thing.

2.4.3.2 Septic Tanks (Interceptor Tanks)

In pressure sewer and small diameter gravity systems the septic tank has often been called an interceptor tank owing to the differences between septic tanks used in conjunction with drainfields versus tanks used on pressure sewer systems. The interceptor tank is generally an engineered product of higher quality, stronger, and more water tight. Except for the possible incorporation of a pump and its containing vault, an interceptor tank is functionally the same as a septic tank.

A comprehensive study on septic tank sludge and scum accumulation was accomplished in the 1940s by the U.S. Public Health Service.[23] Over 600 references were made to develop information from previous research, and practices were reviewed in 12 countries plus the United States. Over 200 operating tanks also were studied, as well as many full-scale laboratory systems. A regression analysis of their observations resulted in equations relating sludge and scum accumulation with time and are presented here as Equations 2-12 and 2-13:

Sludge accumulation:

$$V = 0.7T + 2.12 \qquad \text{Equation 2-12}$$

Scum accumulation:

$$V = 0.45T - 0.12 \qquad \text{Equation 2-13}$$

Where,

V = Volume per capita (cu ft)
T = Time in years

Of the total scum accumulation, about 1/3 was reported to lie above the liquid level, and 2/3 below.

Sludge clear space was described as that distance between the top surface of the sludge and the outlet tee. To avoid scour and carryover of solids, a minimum sludge clear space of 15 cm (6 in) was suggested.

Scum clear space, the distance between the bottom of the scum layer and the outlet baffle or tee (or inlet ports in the pump vault) was recommended to be a minimum 7.5 cm (3 in), but pressure sewer experience suggests 15 cm (6 in) to be a better allowance since scum is a particularly problematic material if allowed to enter the system.

When Equations 2-12 and 2-13 are solved for typical single family occupancies and 3,780-L (1,000-gal) interceptor tanks of usual shape, and using 15-cm (6-in) clear spaces for scum and sludge, the pump vault inlet port level appears best placed at about one-third of the lowest liquid level in the tank.

An audit of septage accumulation was made on the Glide, Oregon STEP system by the Douglas County Department of Public Works. Sludge and scum levels were measured in 400 tanks which had been in service for 8-years. In one analysis of that study, measurements in 186, 3,780-L (1,000-gal) STEP tanks serving single family residences were selected for evaluation. Results are shown in Table 2-4.

From the Glide study and other observations, the following guidelines were proposed for estimating average sludge and scum accumulation at single family residences, with the caveat that accumulations vary greatly from home to home:

1. Annual combined sludge plus scum accumulation: 33 gal/home.
2. Scum comprises about 1/3 of the combined volume of sludge plus scum.
3. About 1/3 of the scum lies above the water (effluent) level.
4. Pump vault inlet ports should normally be located at about 1/3 of the depth below the 'pump off' level.

It has been described that sludge and scum accumulations vary so much as to make accurate forecasts futile.[24] Observations on hundreds of interceptor tanks reinforce his position. However, no better general placement of the outlet ports has been dictated than that given above.

Zoning of the interceptor tank for scum and sludge accumulation and location of the ports in the pump vault are shown in Figure 2-14.

When the pump vault is an integral part of the tank, the liquid level in the entire interceptor tank rises and falls in response to incoming flows and in response to pumping. Although liquid level control settings may vary, typical settings for single home application in 3,780-L (1,000-gal) tanks are 7.5 cm (3 in) between pump off and on, and 7.5 cm (3 in) between on and high water alarm. Most 3,780-L (1,000-gal) interceptor tanks contain about 30 L/cm (20 gal/in) depth, so the 7.5-cm (3-in) settings correspond to about 230 L (60 gal). Figure 2-15 depicts these liquid levels.

The various dimensions may differ as dictated by the individual design engineer. One typical design for a single family residence, using a 3,780-L (1,000-gal) tank and the guidelines for sludge and scum accumulation noted above is given in Table 2-5. (Note that septic tanks normally hold 10 percent more than their rated volume, so a 3,780-L (1,000-gal) tank would contain 4,160 L (1,100 gal) filled).

Table 2-4. **Sludge and Scum Accumulation at Glide, Oregon (186 1,000-gal tanks)**

	Time (yr)	Occupants (No.)	Sludge (gal)	Scum (gal)	Total (gal)
Mean	8.2	2.75	195	92	289
S. Dev.	0.7	1.18	98	60	114
Min.	7.2	1	20	0	60
Max.	9.1	6	530	300	650

This type of table is used to locate the positions of liquid level sensors and pump vault ports, but is not a reliable indicator of the amount of sludge and scum to be accumulated at the time septage removal is necessary. This is because accumulations vary so greatly from home to home. Scum and sludge accumulations at facilities other than single family homes vary considerably. For example, restaurants produce considerable grease; while laundromats produce considerable heavy sludge, but little scum.

2.4.3.3 Multiple-Compartment Tanks

The use of baffled, or multiple compartment septic tanks has often been considered. Objectives have been to reduce the concentration of suspended solids in the effluent, and to limit the consequence of digestion upset. Some have speculated that if septage is not removed as scheduled, flow into the first cell of a two compartment tank may be plugged with sludge or scum before low quality effluent is discharged from the second cell, but this speculation has proven unreliable.

Baffling is sometimes thought to achieve improvement in performance by providing longer detention time, better dispersion, reduced short circuiting, keeping sludge and scum away from the outlet, and reduction of turbulence. But opinion differs as to whether the performance of two smaller tanks (the product of providing baffles) is superior to that of one larger tank.

Studies have been made on the performance of single- and multiple-compartment tanks by the U.S. Public Health Service,[23] Winneberger,[24] Baumann and Babbitt,[25] and Jones.[11] These studies have generally concluded that single compartment tanks are economical, practical, and perform well, but that baffling is advantageous to performance. The degree of improved effluent quality has been described as ranging from "microscopic" to "statistically significant."

Performance varies considerably depending on how compartmentation is accomplished. Two types of compartmented tanks are shown in Figures 2-16 and 2-17. In the former figure, a hole or window is provided in

Figure 2-14. Zoning of a STEP system interceptor tank showing scum and sludge accumulation.

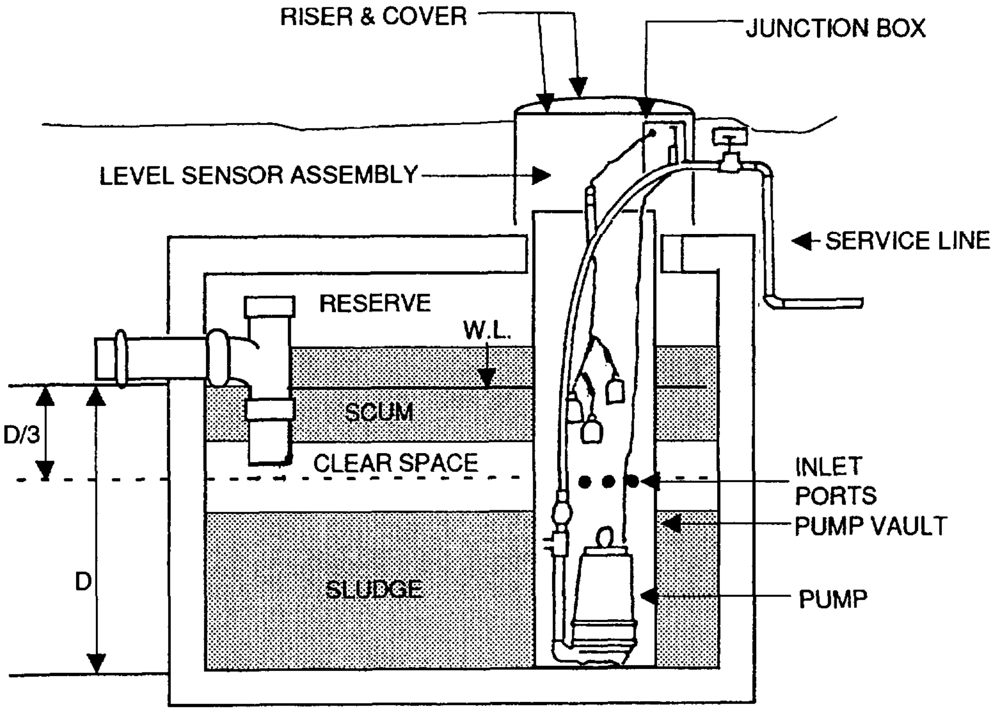


Figure 2-15. Zoning of a STEP system interceptor tank showing liquid levels at pump off, on, and high level alarm.

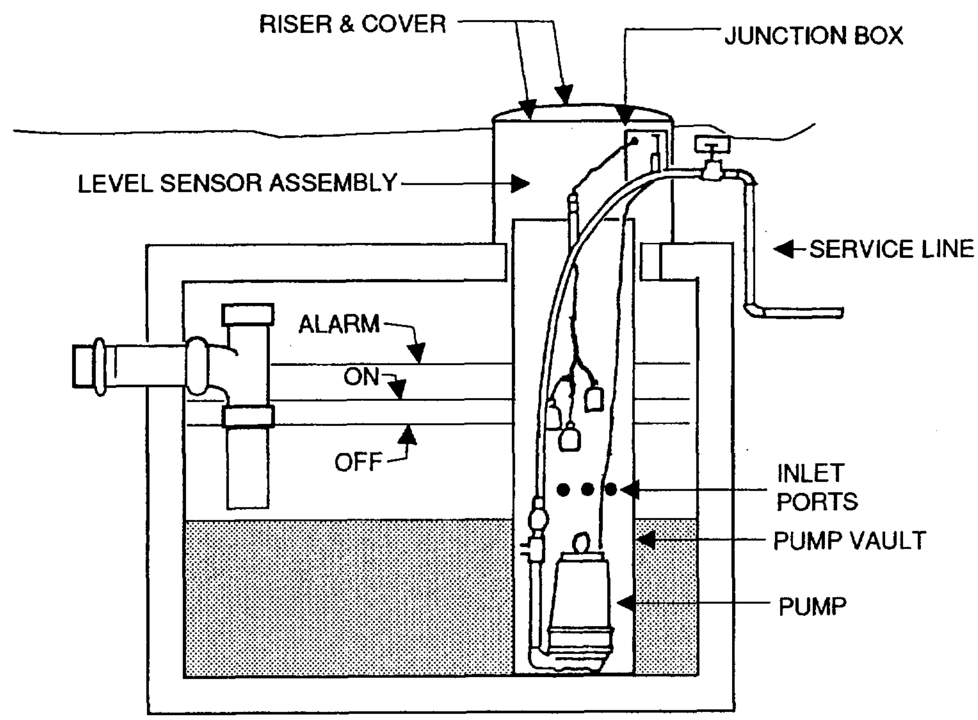


Figure 2-16. **Two-compartment interceptor tank with hole in baffle wall where clear space expected.**

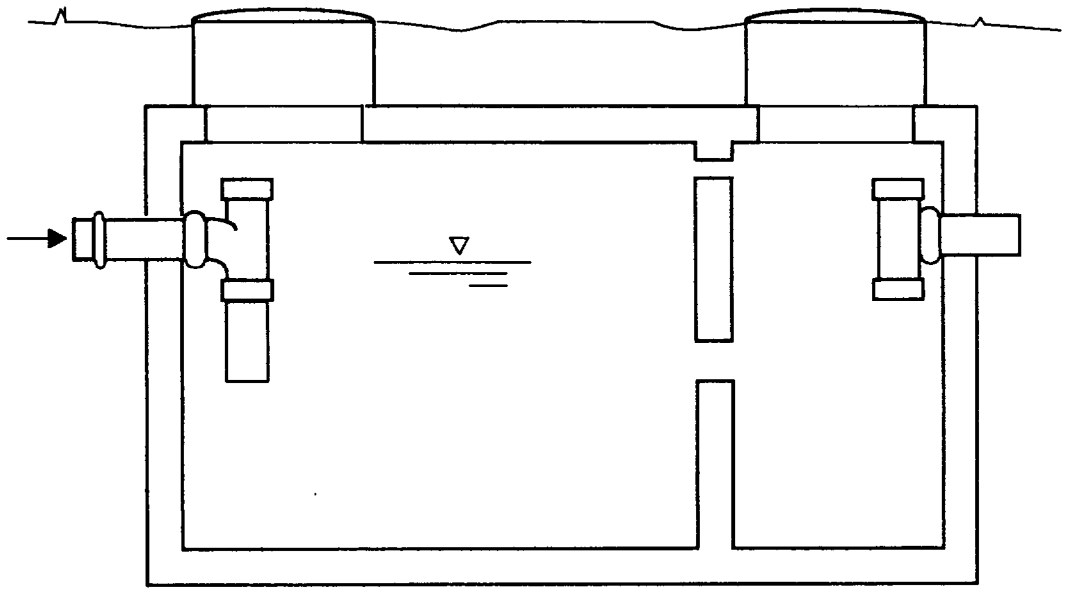


Figure 2-17. **Two-compartment interceptor tank using combination tee and 1/4 bend.**

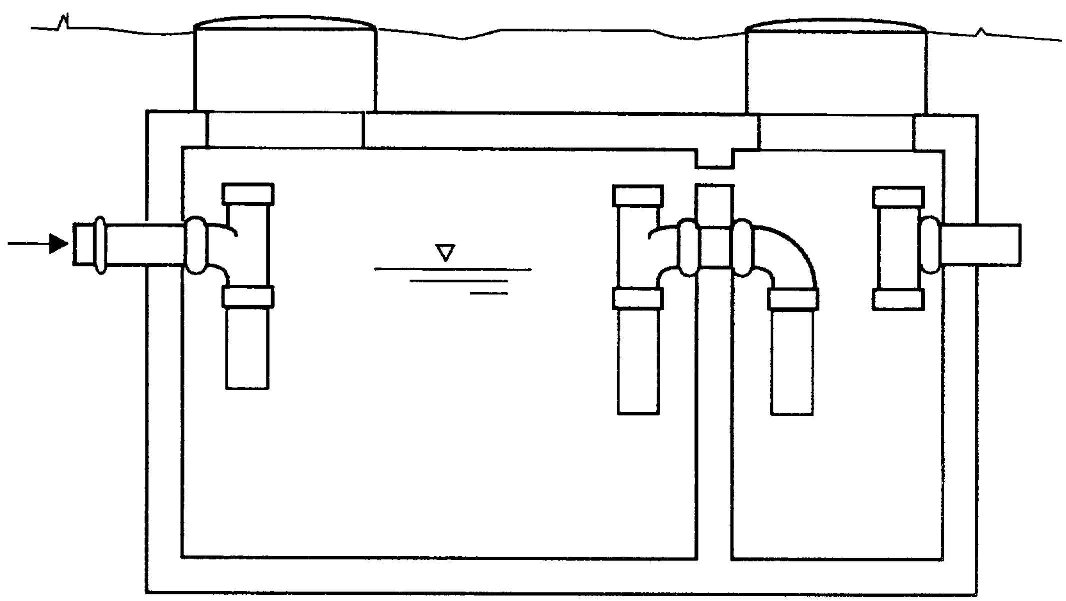


Table 2-5. Typical Zoning Design For a 1,000-gal Interceptor Tank Serving a Single-Family Residence

Parameter	Volume (gal)
Sludge	370
Sludge clear space (6-in)	120
Scum clear space (6-in)	120
Submerged scum	120
Floating scum	60
On-off pump cycle (3-in)	60
On-alarm (3-in)	60
Reserve space*	190
Total	1,100

* Reserve is 720 L (190 gal) above the alarm level when there is 230 L (60 gal) of floating scum, or 950 L (250 gal) when there is no floating scum.

the baffle wall separating the two cells, placed in the center of where the first compartment clear space is expected to be. The latter figure shows a combination tee and 1/4 bend with the invert placed at the liquid level of the first cell, and the inlet located in the clear space of the first cell. Generally, the latter design has been credited as providing the better performance.

If an internal pump vault is placed in the second cell of the tank, as shown in Figure 2-16, the liquid level will rise and fall throughout the full length of the tank in response to pumping, as shown in Figure 2-15.

However, if an internal pump vault is placed in the second cell of the tank shown as Figure 2-17, the liquid level fluctuates only in the second cell. If the second cell is small and if the usual zoning volumes are used between pump off, pump on, and high level alarm (normally about 230 L [60 gal] each), the liquid level fluctuations may be considerable. This causes the liquid level within the second cell to be quite low at pump off level, and subjects the tank to a more unbalanced structural loading due to the soil backfill. This has been of most concern when flexible, plastic septic tanks, or concrete tanks of marginal strength are used.

Baffle walls must be made strong enough to withstand the liquid level being at operating height on one side of the wall, but with the other cell being empty. This has been difficult to accomplish with some plastic tank designs.

Experience with thousands of single-cell septic tanks used on STEP systems has shown a single riser to be sufficient. If multiple cells are used, each cell must be fitted with a riser to provide access for septage removal.

To further evaluate multiple-compartment tanks, the purpose of the tank as used in a STEP system should be reviewed. If discharge is to a municipal treatment works, the purpose is generally to capture the grit, grease, and stringy material that would present a problem to pumping, foul the liquid level sensors, and possibly cause obstructions in the piping system.

Single-cell tanks have been used extensively and perform satisfactorily for this purpose. Pump clogging occurs in only about one percent of the installations annually. Clogging of mains is nonexistent. It seems little benefit would be derived by the use of multiple-compartment septic tanks.

If, however, discharge is made to a soil absorption field or other similar facility where the maximum reduction of suspended solids may be critical, properly designed multiple compartment tanks will perform better functionally.

The need for quality, structurally adequate, infiltration-free tankage is usually regarded as more apparent than the need for compartmentation. However, research on tank shape, inlet and outlet fittings, gas baffle deflectors, and other design factors is encouraged.

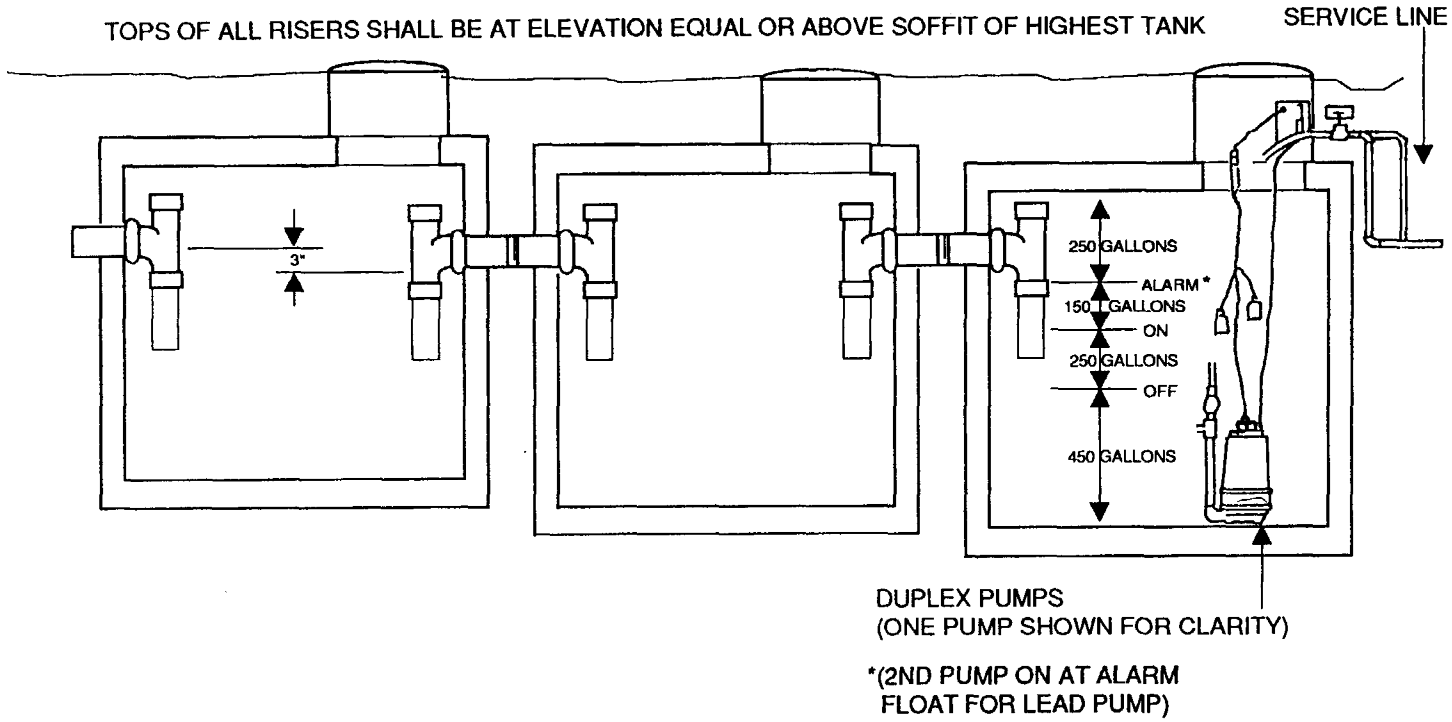
2.4.3.4 Tanks Serving Multiple Homes

Most projects standardize on 3,780-L (1,000-gal) tanks to serve any size home, and are used to serve up to 3 homes. The benefits of standardization outweigh the benefits of variable tank sizing. However, the frequency of septage pumping increases, but not proportionately, with the number of people served.

When MEDU installations are made, such as to serve a restaurant, apartment complex, mobile home court, or other facility having flows greater than that expected from about 3 EDUs, larger tankage is needed. The use of precast tanks placed in series has been successful. Multiple tanks in parallel have experienced problems in dividing flows evenly. In some cases single large precast tanks have been used. In a few cases, large tanks have been cast in place, but this practice is often the least desirable option due to site disruption.

Figure 2-18 shows a MEDU installation using precast tanks placed in series. Two pumps are placed in the final tank. To make use of reserve space within the tanks without breaching the lowest tank riser, all risers should extend at least to the elevation of the soffit of the highest tank. It is often impractical to provide as much reserve space in the tanks as would be desired, in which case emergency overflow to an existing or new drainfield is sometimes provided.

Figure 2-18. Multiple-unit interceptor tank and pump assembly.



To insure ventilation between tanks, even if the liquid level in any tank is higher than the crown of the inlet or outlet fittings, a small pipe "jumper" may be placed to join risers.

Sizing relies in part on the judgment of the engineer, with regard to flows and to character of the wastewater. Expectations of sludge and scum accumulation are guided by experience with the types of facilities being served. Sizing of MEDU grinder pump vaults follows conventional sewerage pumping practice.

One method used for septic tank sizing is provided by Equation 2-14:[26]

$$V = 0.75Q + 1{,}125 \qquad \text{Equation 2-14}$$

Where,

V = Volume of septic tank (gal)
Q = Daily flow (gpd)

Daily flow can be estimated by making comparisons with similar facilities in the area having metered water. Other methods are described in the *Design Manual for Onsite Wastewater Treatment and Disposal Systems.*[26]

As for septage removal frequency, experience with hundreds of interceptor tanks on pressure sewer systems has shown that tanks which meet the above criteria serving typical single-family residences require pumping at about 10-yr intervals. However, septage accumulation varies widely from home to home, and an interval of about 8 yr is often adopted.

The best method is to remove septage when it begins to encroach on the clear space minimums, which requires measurements using devices described best in several publications.[23,24,27] Septage removal from tanks discharging to soil absorption fields should be more frequent due to the variability of septage accumulation and due to the severe damage caused if solids are discharged to them.

MEDU establishments such as restaurants require septage removal much more frequently. Restaurants discharge large and troublesome volumes of grease and the extremely hot dishwasher water adds to the problem. Excess grease should be removed prior to discharge to the interceptor tank. Methods of accomplishing this are outside the scope of this document, but are presented elsewhere.[11,23,28]

2.4.4 Pumps/Electrical Service

2.4.4.1 Pumps

a. General

Centrifugal pumps are most commonly used, followed by progressing cavity pumps. Submersible water well pumps having 5 or more stages (impellers) are sometimes used on STEP systems, and pneumatic ejectors have seen limited use in the past, but none are presently being marketed.

For approximate estimations of horsepower required for particular head and flow conditions, the following equation can be used. Equation 2-15 has been derived from the definition of horsepower being 33,000 ft-lb/min, and the weight of water being 8.34 lb/gal:

$$H_p = QH/(3{,}960E) \qquad \text{Equation 2-15}$$

Where,

H_p = Horsepower
Q = Discharge rate (gpm)
H = Head (ft of water)
E = Pump and motor efficiency (%)

Equation 2-15 is used for only the most general purposes since pump selection depends considerably on specific pump characteristics. It is used, however, in conjunction with pump characteristic curves or testing data to determine efficiency.

The ability of a pressure sewer pump to run at shutoff head is a consideration. Shutoff head conditions occur when an isolation valve has been closed, or following a long power outage when many pumps run simultaneously, dominating some of the pumps to shutoff head.

Some pumps have the ability to run dry for extended periods. A dry running condition occurs when the pump has become air bound or when the "off" liquid level sensor malfunctions.

If the liquid level in the pump tank is higher than the hydraulic grade line of the main, siphoning to the main can occur after the pump motor has turned off. This can lower the liquid level in the pump vault to the elevation of the pump intake, allowing air to be drawn into the pump and causing some pumps to become air bound.

In areas where the power supply undergoes extremes of voltage variation or brownouts, motors tolerant of these conditions may be preferred, such as permanently split capacitor (PSC) motors.

b. Centrifugal Pumps

The most common GP or STEP pressure sewer pump is the submersible centrifugal.

The head-discharge curve is typically shaped as shown in Figure 2-19a. When two or more pumps discharge simultaneously into a common header the abscissas are additive, and the resulting curve is as shown in Figure 2-19b. Because in pressure sewer use the pumps are located at different stations and different elevations along the main, the analysis becomes more detailed. This procedure is given by Flanigan and Cudnik.[13]

Since the pump discharges via a service line to a pressure sewer main, headlosses in the service line can be subtracted from the ordinates of the pump H-Q curve to form the effective pump curve at the main, as shown in Figure 2-20.

Centrifugal pumps draw most power at maximum discharge, at the far right of the H-Q curve, and draw the least power at shutoff head. Efficiencies are shown on some published curves, with greatest efficiency usually being about mid point on the curve.

STEP system centrifugal pumps can discharge light solids that may be present in septic tank effluent. Typically the pumps can handle solids ranging from 6-mm to 18-mm (0.25-0.75 in) diameter. Small solids handling pumps, intended for raw wastewater use, can pump solids of about 5-7.5 cm (2-3 in) in diameter. Grinder pump impellers can handle only small solids since the pumping of large solids is not necessary due to the grinding action.

STEP impellers are usually made of bronze or plastic. If a pump having an iron impeller sets in septic wastewater without operating for a while, e.g. when the homeowner is on vacation, the impeller can become bonded to the volute by iron sulfide. Often the motor will not have enough starting torque to break the impeller loose from the iron sulfide, occasioning a service call. Bronze and plastic impellers are generally more resistant to this bonding than iron impellers.

Some grinder pumps use iron impellers, but have fewer occasions of iron sulfide binding than STEP pumps because the GP uses a higher horsepower, higher starting torque motor and the wastewater is less likely to contain sulfide species at the pump vault than a STEP system.

Iron sulfide plates onto the iron casing, especially in STEP systems. In most cases the effect is only cosmetic, but in some cases corrosion and metal loss occurs. The corrosion depends on the sulfide generating potential of the wastewater (e.g. sulfate in water supply, BOD, and temperature). If the pump is constantly submerged it will normally corrode less than if it is sometimes exposed to the atmosphere.

Most centrifugal, submersible pumps used on pressure sewer systems can operate at shutoff head without damage for extended periods. Some engineers specify that a 3-mm (1/8-in) diameter hole be provided in the pump casing, to leak slightly during shutoff conditions, causing circulation and cooling. Since the holes tend to clog, some engineers favor using orifice bleeder valves for this purpose. These are simple, neoprene valves that have a flapper to partially close the orifice during discharge.

Most submersible pumps can run dry for extended periods without damage. Dry running is often caused by an air bound condition following siphoning. To prevent siphoning, a hole or orifice bleeder valve is sometimes provided to admit air and break the siphon. The hole or valve can also allow the air to escape, preventing air binding even if siphoning occurs. With STEP systems using pump vaults inserted in the interceptor tank, uncontrolled siphoning can cause the pump vault contents to be lowered such that the pump vault can float out of position.

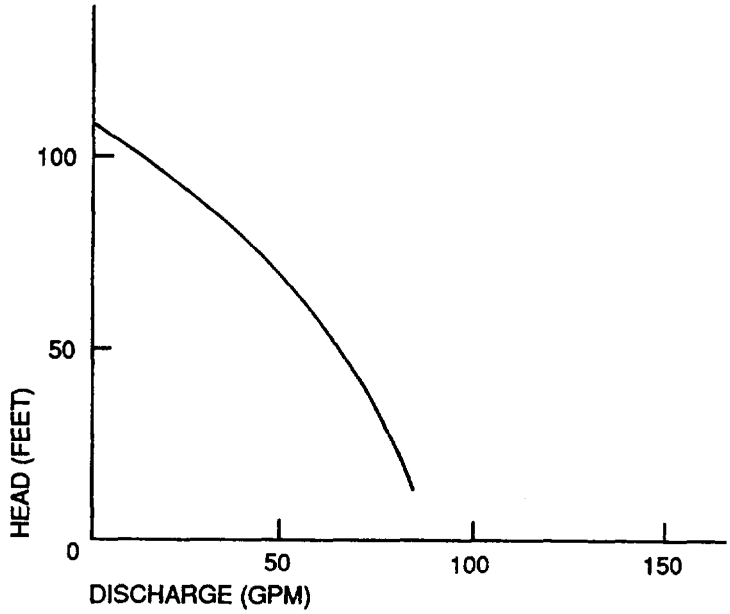
Most high-head centrifugal pressure sewer pumps use 3,450-rpm, 2-pole motors rather than slower running 1,725 rpm, 4-pole motors.

In general, for centrifugal pumps steeper H-Q curves and higher heads are obtained by the impeller being shallow (having less solids handling capacity), having fewer vanes, and having more wrap to the shape of the vanes. Larger diameter impellers are associated with higher heads. There are various impeller designs, such as enclosed, open, and vortex. Each type and design has its own characteristics.

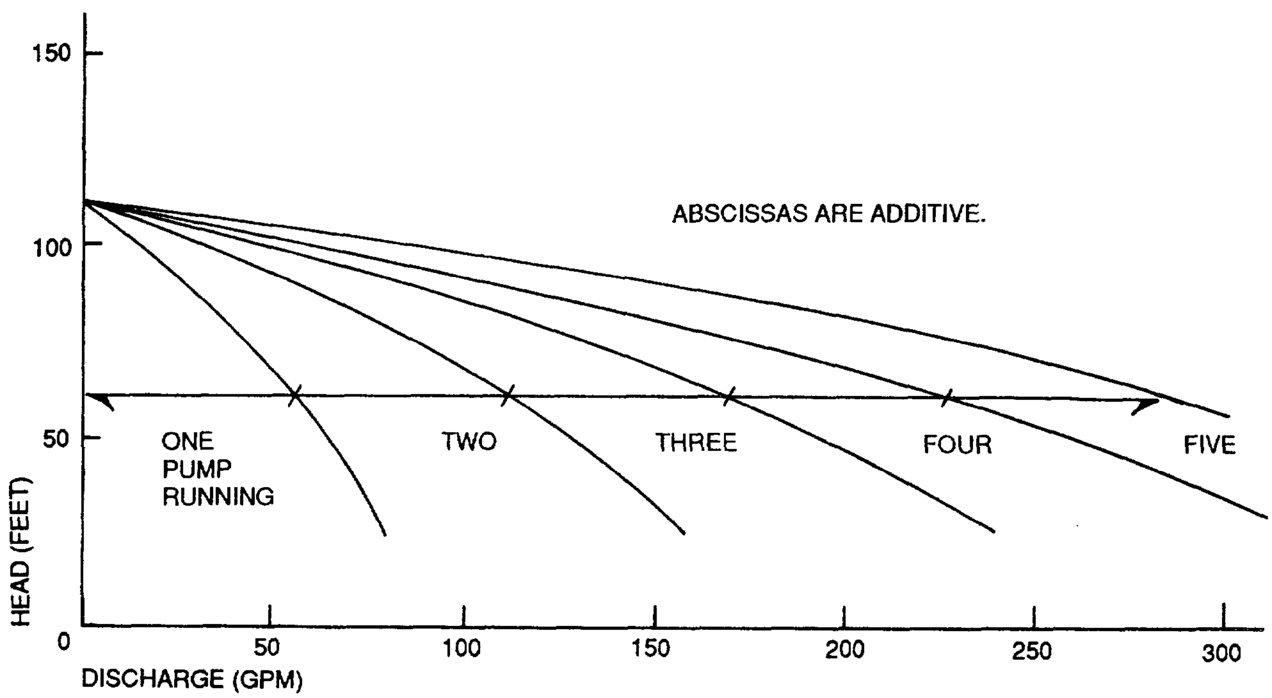
Submersible, multiple stage water well pumps are small and light-weight which make them easier for field personnel to handle. Due to the multiple stages, high running speed, and shallowness of the impellers, high heads are achievable using fractional horsepower motors. Well pumps are damaged if run at shutoff head, so employ the drilled hole or bleeder mentioned previously to leak sufficient flow to lubricate the pump and to keep the motor from excessively overheating.

If run at excessively high heads, a well pump develops a downthrust condition, and if run at excessively high discharge rates, an upthrust condition develops. To limit the latter condition an orifice restriction is sometimes

Figure 2-19. **Head-discharge curves for one and multiple centrifugal pumps in parallel.**

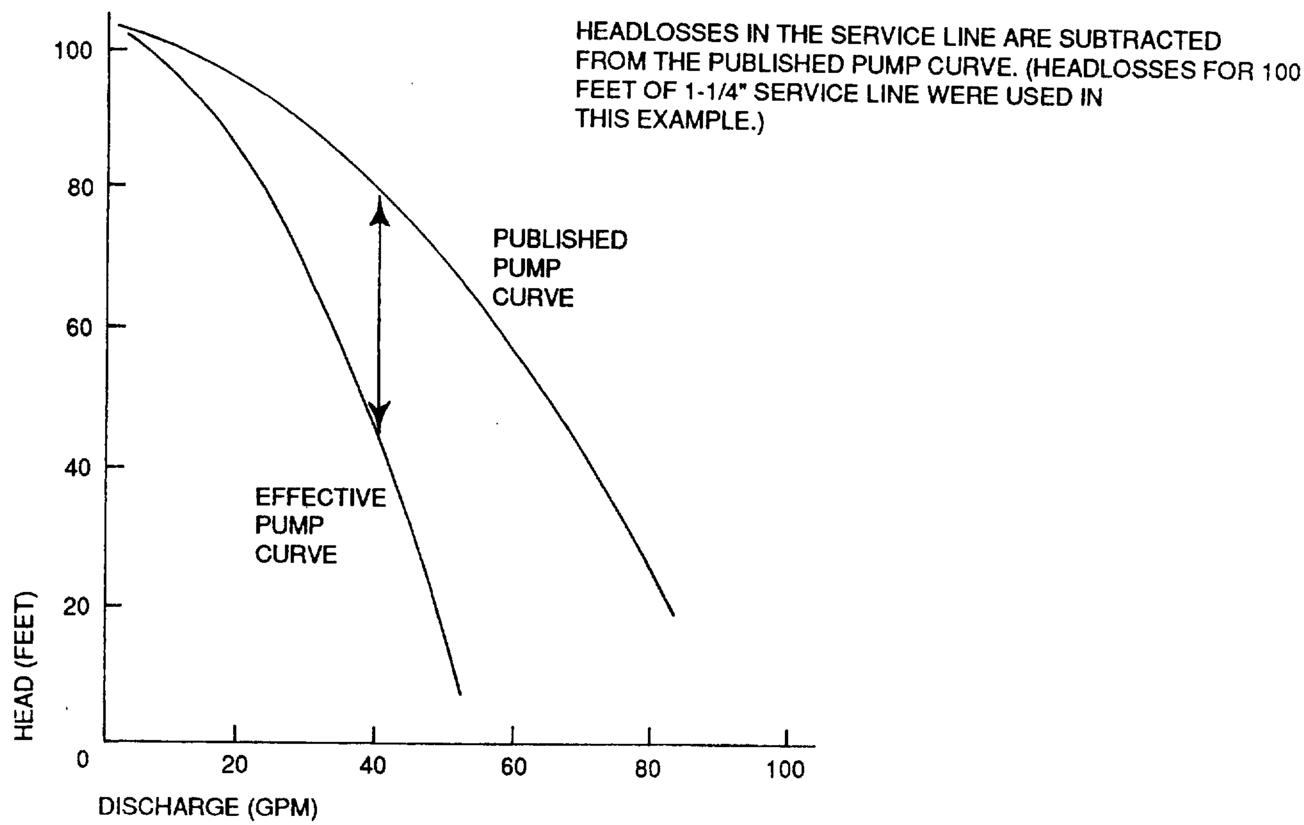


a. Single pump H-Q curve



b. H-Q curves for multiple pumps

Figure 2-20. Effective pump curve.



and consequently preventing the pump from running at too high a discharge rate.

Well pumps must be used in conjunction with screens or filters, since they have no solids handling capability. They must also be installed in a sleeve resembling a well casing, so water flows past the motor to provide cooling.

c. Progressing Cavity Pumps

A progressing cavity pump is a semi-positive displacement, screw type-pump consisting of a single helical rotor turning eccentrically in a double helical elastomeric stator having twice the pitch length of the rotor. This forms a series of spiral shaped sealed cavities that progress from suction to discharge. Figure 2-21 shows the rotor and cutaway stator of a progressing-cavity pump.

Most progressing-cavity pumps used on pressure sewer systems have the pumping elements submerged, but dry well installations are sometimes used. The progressing-cavity pump self-primes reliably.

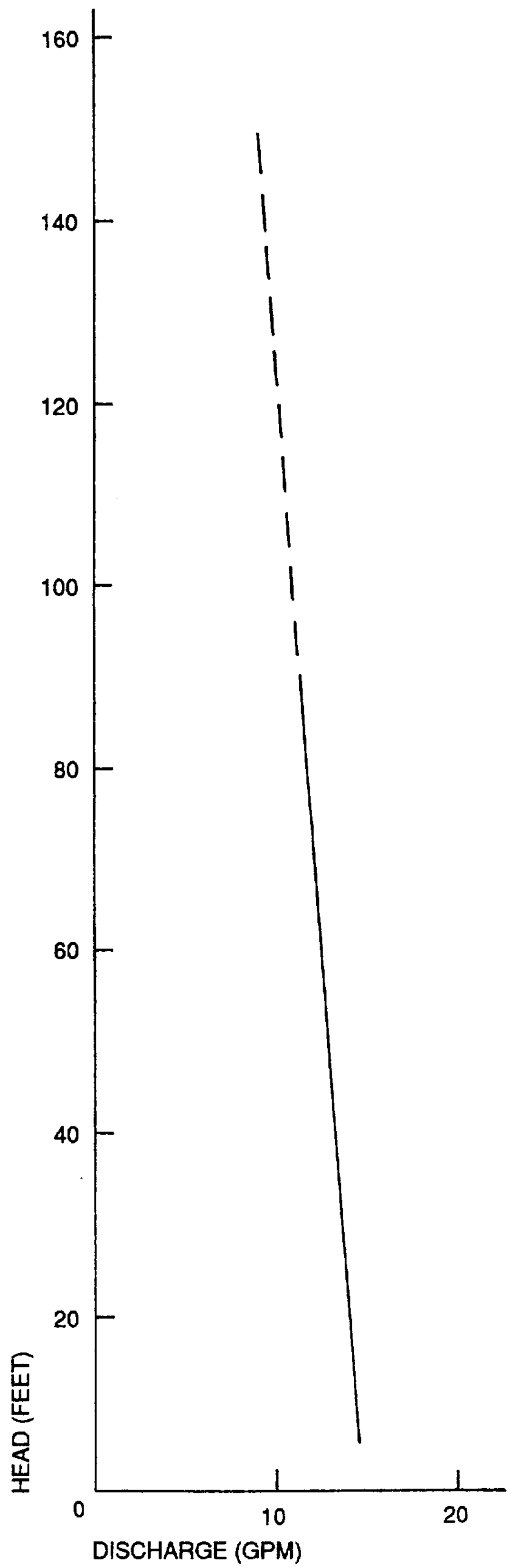
A typical head-discharge curve is shown as Figure 2-22. The H-Q curve is steep, discharging a predictable flow rate. The mid range discharge rate is generally adopted as the pump flow rate, irrespective of the slight change caused by head variation. When numerous progressing-cavity pumps discharge simultaneously into a common header (pumping in parallel), the resulting flow is taken as the adopted discharge rate for one pump times the number of pumps running. This is in contrast to centrifugal pump analysis where the composite pump curve is plotted, and the discharge rate is taken to be the intersection of the composite curve and the system curve.

The power draw of a progressing-cavity pump increases with increasing discharge pressure.

Progressing-cavity pumps do not have a natural shutoff head but instead continue increasing pressure within the capacity of the motor and the ability of the components to withstand the pressure. If run against a closed valve, amperage draw increases and the thermal overload eventually trips out, shutting off the motor. After cooling, the thermal overload automatically resets and the pump

Figure 2-21. **Rotor and cutaway stator of progressing cavity-type pump.** (Courtesy of Environment/One Corp.).

Figure 2-22. Typical progressing-cavity pump H-Q curve.



tries again to discharge. If the valve is still closed, the thermal overload again heats and trips out, and the process repeats. The thermal overloads used are capable of withstanding this duty.[2]

If the closed valve was located right at the pump discharge, the stator would likely be destroyed by running at excessively high pressure. However, in pressure sewer applications some air is normally present in the piping system to cushion the effect, so a closed mainline isolation valve may present a less severe condition.[12]

Some installations use a pump-mounted pressure relief valve to avoid overpressure conditions, some rely on the protection provided by the motor thermal overload, and others sense the discharge pressure and turn off power to the pump motor until the high pressure condition has been corrected.

The stator will be destroyed if a progressing-cavity pump is run dry, and if the dry running continues, the rotor and other components will be damaged. However, if the rotor and stator are wet enough for lubrication they can be run without damage.

Progressing-cavity pumps do not become air bound, but anti-siphoning devices are recommended to be used with them to prevent air release into the pressure sewer and to keep the rotor and stator lubricated.

Four-pole motors, running at 1,725 rpm are used.

2.4.4.2 Electrical service

Most grinder pumps and solids handling pumps, which require more starting torque than effluent pumps, use capacitor start-capacitor run (CSCR) motors, and some use capacitor start-induction run (CSIR) motors. Centrifugal effluent pumps use CSIR or permanently split capacitor (PSC) motors, and some fractional horsepower effluent pumps use shaded pole (SP) motors. Nearly all motors have automatic reset thermal overload protection built in.

Power consumption is normally low; often less than \$1.00/month. Power use can be estimated by Equation 2-16, or more correctly by Equation 2-17:

$$P = 745\, H_p\, T \text{ (approximate)} \qquad \text{Equation 2-16}$$

$$P = T\, I\, E\, F \qquad \text{Equation 2-17}$$

Where,

P = Power consumption (watt-hours)
H_p = Horsepower

T = Running time (hours)
I = Amperage
E = Voltage
F = Power factor (percent)

As points of reference, typical power factors are about 50 percent for CSIR motors, and higher for PSC motors. CSIR motors will generally draw more amperage than PSC motors.

Malfunctions of the liquid level sensors are a major cause of service calls. Accordingly, special attention should be given to specifying good sensors and applying them properly.

Mercury float switches have been the most commonly used liquid level sensors. One float is required for pump off, one for pump on, and one for high level alarm. If redundant off is desired, an additional switch is used. Duplex installations add one more switch for lag pump on.

Most mercury float switches are pilot devices that control the motor start contactor (relay) in a control panel, but some are motor rated. Some variations of mercury float switches provide a differential so that one float can control both pump on and off. Motor rated, differential switches are sometimes used on economically motivated installations.

Grinder pump and solids handling pump systems encounter rags and grease in the raw wastewater that interfere with the movement of mercury switches. Larger size floats have generally been more reliable.

Some STEP pump vaults are so small that the mercury switches have little room to operate. Also, when the pump vault is internal in the septic tank the differential between floats is small (typically about 7.5 cm [3 in]). The small space and small differential require that the mercury switches be given a short tether. The short tether and the likelihood of the switches coming in contact with pumping equipment in the vault often cause these installations to be unreliable.

Displacer-type liquid level sensors have seen limited use. Displacers are floats that move vertically in the pump vault, thus conserving space and presenting fewer opportunities for being obstructed. Most displacers are built to provide a differential between pump on and pump off. Some are pilot devices, while others are motor-rated.

Bubbler type liquid level sensors have also been used. These consist of a small compressor which purges air down a sensing tube in the wet well. The pressure in the sensing tube increases as the liquid level in the wet well rises. Pressure switches in the control panel sense the pressure to turn the pump on or off, or to activate alarms.

Bubblers are more common than mercury switches on pressure sewer installations in Europe. In the U.S. their use is usually limited to more expensive installations, or they are used where the liquid level sensors must be "explosion proof"-rated. To achieve that standard, mercury switches use intrinsically safe relays which are expensive, complicate the control panel, and have had a history of being troublesome.

Environment-One uses a trapped air system, similar to the bubbler but without the compressor.

Numerous other level sensing methods have seen limited use, such as diaphragm switches, reed switches, probes, transducers, and ultrasonics.

The electrical control panel is usually mounted on the outside wall of the home, but is sometimes placed on a pedestal near the pumping unit.

Features of the control panel vary greatly depending on the choices of the designer. Figure 2-23 shows typical, simple control panel circuitry using mercury float switches. This controller depicts a 120-volt panel not requiring a panel mounted capacitor, and works as follows:

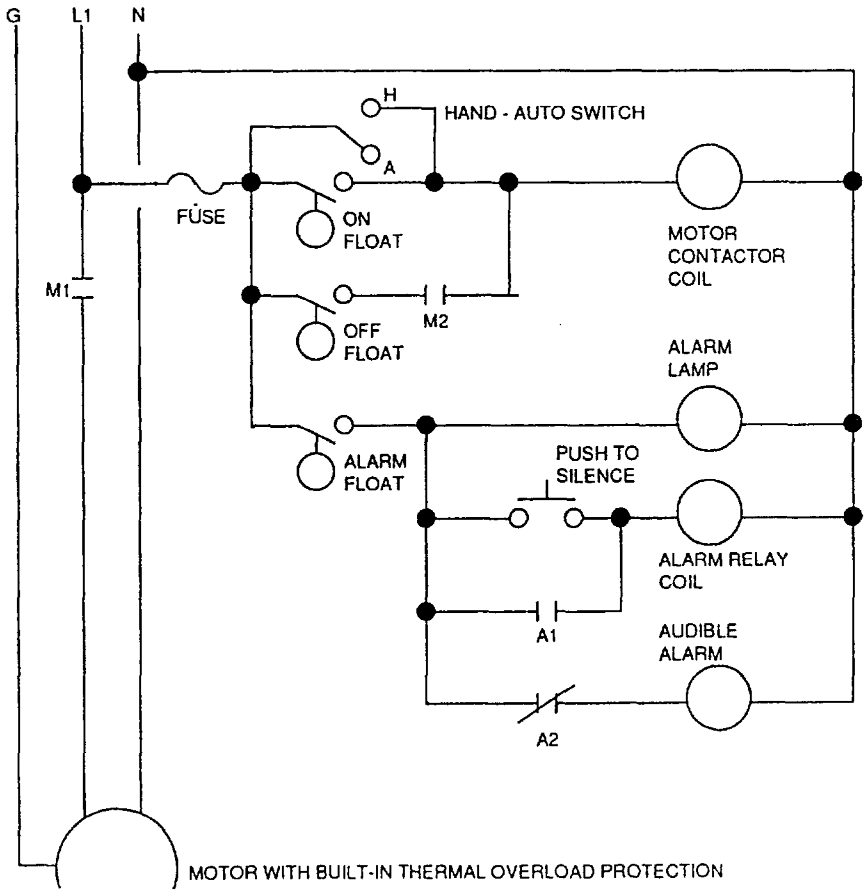
Assume the hand-auto switch is in the auto position, in which case that circuit is open. In the hand mode, the switch powers the motor contactor coil. Off is often provided by the fuse or circuit breaker being openable.

As the liquid level in the wet well rises, the off float is closed and eventually the rising water closes the on float. Power then passes through the closed on float switch to the coil of the motor contactor, which electrically closes and holds contacts M1 and M2. M1 being closed, power is provided to the motor.

The pump motor is now running, so the liquid level in the wet well is receding. As the liquid level in the wet well recedes, the on float opens but the motor contactor coil remains energized via the still closed off float and the closed contact M2. As the liquid level continues to fall, the off float switch opens, discontinuing power to the motor contactor coil and opening contact M1 which stops the motor and opening contact M2 so the motor contactor coil no longer receives power via the off float.

If the liquid level in the wet well rises above the on float and continues rising, it eventually causes the alarm float switch to close. This provides power to the alarm lamp.

Figure 2-23. **Circuit diagram of a basic 120-volt control panel.**



Power is also applied to the audible alarm via a normally closed contact A2. The alarm may be silenced by pushing a button mounted on the control panel door. This energizes the alarm relay coil, opening contact A2 and closing contact A1. The alarm relay coil remains energized via the now closed contact A1. When the high liquid level condition has been corrected, the alarm float switch opens and the alarm circuitry is automatically restored to the condition shown in the figure.

A simple panel might have the following features:

1. Motor start relay
2. Audible high water alarm
3. High water alarm light
4. Control circuit fuse
5. Audible alarm push button silence
6. Audible alarm automatic reset relay and circuitry
7. Power leads accessible for taking amperage readings
8. Hand-off-auto (HOA) toggle switch
9. Terminal strip

If the pump uses a capacitor start motor, the capacitor may be in the control panel or it may be mounted on the motor. With a capacitor start - capacitor run motor both capacitors are in the control panel.

Numerous additional features can be added to control panels.

In some cases they have proven to be detrimental owing to the complexity produced. This is particularly the case if the service personnel that maintain them are not accomplished in electrical matters.

Care should be exercised in providing a proper balance of control panel features versus the benefits of simplicity.

Additional features sometimes used in control panels:

1. Elapsed running time meter
2. Event counter
3. Power failure alarm
4. Overload protection in addition to that built in the motor
5. Various switches and status lights
6. Low voltage transformers
7. Seal failure lights

On STEP systems having a mixture of 115- and 230-volt motors, it has been common to provide 230-volt power with neutral to each control panel. In that way, either voltage pump can be run.

A junction box is used at the pumping unit to join the mercury switch wiring and pump wiring to the branch wiring extending from the pumping unit to the control panel. This wiring is either rated for direct burial or is placed in a conduit. Each mercury switch uses two conductors and the pump uses 3 conductors. Accordingly, a typical installation involving a pump and 3 mercury switches requires 9 wires. One leg of each mercury switch can be commoned, so 7 wires extend from the pumping unit to the panel.

Junction boxes have often been a maintenance problem due to leakage and corrosion. Splices made inside them should be made watertight. Corrosion-resistant materials should be used on the junction box. Abundant room for access to the junction box is required for ease of service.

On some installations the pumping unit is placed so near the home that wiring can be run directly from the pumping unit to the control panel without need for a junction box. The conduit must be perfectly sealed to prevent the migration of corrosive and flammable gases to the panel.

The use of simple and easily understood electricals is generally advised. Thought must be given to electrical safety and to the certified electrical qualifications of the workmen. Familiarity with the National Electrical Code is required. Some electricals are listed by testing laboratories, e.g. Underwriters Laboratories, Canadian Standards Association, or Factory Mutual. This provides a measure of protection from electrical shock and from concerns over liability.

Power can be taken from the homeowner's load center (the circuit breaker panel). If the panel has no remaining space, sometimes two wafer breakers can be used in place of one standard sized breaker. Circuit breakers should be clearly marked for identification.

A problem in using the homeowner's load center is that access into the home is usually required which is a practice generally avoided by contractors and engineers. When the load center is used, the homeowner is typically required to provide the branch circuit to a specified location, instead of the work being included in the contract. Sometimes the work is improperly accomplished or not done in the time required.

An alternative to the use of the homeowner's load center is to take power from the meter base. In this case the power is run hot from the meter base to a fused safety switch placed as close to the meter base as possible. Use of this option requires specific approval of the regulatory authorities, such as the state electrical inspector and/or the state fire marshal, and also the approval of the electric utility.

2.4.5 Valves/Cleanouts

2.4.5.1 Mainline Isolation Valves

Isolation valves are used on pressure sewer mains to close a reach of the main for repairs if necessary, and to accommodate pressure testing of limited lengths of main. In some cases plastic valves have been used, generally ball valves, but more commonly bronze gate valves are used in sizes up through 7.5-cm (3-in) diameter, and epoxy coated cast iron valves are used in larger sizes.

Bronze and cast iron are subject to plating with sulfide, but generally have performed well. This assumes the pipeline flows full as opposed to being exposed to air at the crown. If air (gases) were present there, the hydrogen sulfide gas present could be converted to sulfuric acid. If the pipeline flows full, the corrosive acid cannot form.

Standard AWWA gate valves have been used but those using a resilient wedge and closing on a smooth bore have been found to close more tightly.

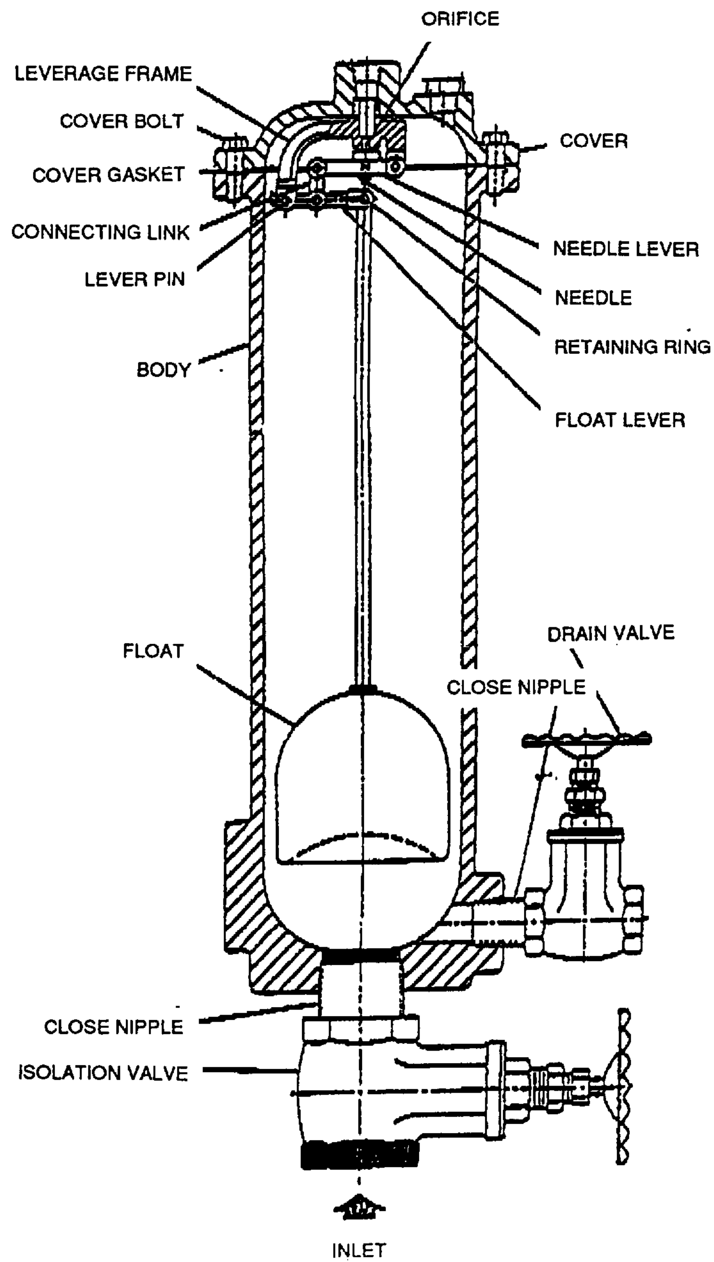
2.4.5.2 Air Release Valves

A common air release valve is shown as Figure 2-24. The valve inlet is connected to the top of the main. If the valve itself is placed to one side of the main, a service line can be used for the connection. The service line connects to the top of the main (where air is accumulated), and slopes continually upward to the valve inlet.

Normally the body of the air release valve is partly full of water (effluent). If it is full enough to buoy up the float, the rubber needle closes the orifice that passes through the top of the valve body. As air (or gas) enters the valve from the main, the trapped air accumulates and the liquid level in the valve body is correspondingly lowered. Finally enough air is trapped that the liquid level is lowered enough that the float is no longer buoyed up. When this happens the needle falls away from the orifice seat and the previously trapped air is expelled out the orifice.

The air release valve can also admit air under vacuum conditions. If the main undergoes a vacuum, as happens when siphoning occurs, the effluent in the valve body is drawn out of the valve and into the main. Since there is

Figure 2-24. **Wastewater-type air release valve.** (Courtesy APCO Valve and Primer Co.).



no effluent in the valve body to buoy up the float, the rubber needle falls away from the orifice seat. Air can then be drawn into the valve and into the main by the vacuum, through the orifice.

The amount of air that an air release valve can release or admit depends on the orifice size and the pressure differential across the orifice. For perspective, a 8-mm (5/16-in) diameter orifice will pass about 7 L/s (15 cfm) of free air at 6.9 kPa (1 psi), and about 5 L/s (20 cfm) at 69 kPa (10 psi).

Automatic air release valves should be wastewater type. Water system valves have occasionally been used but they usually become inoperative due to a gel-like accumulation. Also, water type valves may be produced from materials not sufficiently corrosion resistant, and they may have unsuitable opening sizes.

A soft durometer needle should be used where pressure is low, which is typical of pressure sewer application. Also, a large orifice size needs to be specified, for example 8-mm (5/16-in) diameter, to accommodate the comparatively large volumes of air in and out of the valve under the low pressures involved. The valve manufacturers should be consulted for guidance.

The valve bodies are cast iron, thoroughly epoxy coated. Working parts should be Type 316 stainless steel or a plastic proven by experience to be suitable.

Air release valves, not vacuum valves or combination air release and vacuum valves, are typically sufficient, but standard hydraulic evaluations would apply.

Because of the possible odor, air release valves are often vented to soil beds for odor absorption. Activated carbon canisters have also been used for treatment of off-gases, but with only limited success. Further data are presented elsewhere.[29] When the valves are located distant from dwellings and/or where they are expected to expel little gas they are normally vented to atmosphere, in which case the discharge needs to be vented outside of the valve box or the valve, box and appurtenances must be made of corrosion resistant materials.

Soil beds used for odor absorption generally consist of a perforated pipe bedded in gravel, underlying at least 45 cm (18 in) of loam soil backfill. Drainage should be provided if the soil bed is located in an area of high groundwater. Sizing depends on the volume of gas expected, but usually soil beds are greatly oversized as the extra sizing is low in cost and provides a generous assurance that the bed will perform despite possible adverse conditions.

Where the location of air release facilities be precisely determined, manifolded connections to the main may be made. These manifolds should include a connection several pipe diameters below the point where a hydraulic jump would form.

The geometry and valving should be such that each connection can be flushed clean by maintenance staff.

2.4.5.3 Cleanouts

Where cleanouts are used on the mains they usually are pipe cleaning pig launching stations. These are placed at pipeline terminations and where pipe diameters change. Mostly they are used to insure that the pipelines are clean of construction debris following pipeline installation. This removes the speculation of debris-caused blockages in the event that hydraulic anomalies occur.

The cleanouts typically extend to ground surface and may constitute summits that accumulate air (gas). Manual air releases are usually fitted to them.

2.4.5.4 Service Line Valves

Most of the valves and appurtenances available were conceived and designed for purposes other than pressure sewer use. They may work well on this application, or they may not. Advice is to proceed cautiously, and if at all possible, to see that the product has been used successfully on previous installations with the same application.

Corporation stops are often used at the main, fastened to the service saddle. Being difficult to replace, a quality product is desired. They are bronze, and should be full port opening.

Bronze gate valves have been used as isolation valves. These tend to perform well but do not seal drip tight. Unless high quality valves are used the handles corrode when exposed to soils and moisture, and they corrode badly if exposed to the wastewater atmosphere.

Plastic ball valves have been successfully used. These close tightly and because of the 1/4 turn of the handle, it is easy to see at a glance if the ball valve is open or closed. Union type valves are preferred, but if buried there is no access for adjusting the union. Perhaps surprisingly, some plastics become brittle due to exposure to hydrogen sulfide. Other plastics are not strong enough to withstand external forces, such as differential settlement. The proper material should be specified, such as PVC. Most manufacturers offer tables showing the corrosion resistance of their materials.

Two check valves are often used on services, with one being located at the pumping unit and the other being buried at some designated point along the service line, such as at the street right of way line or near the main. Service lines are quite subject to damage by subsequent excavations. The purpose of having two check valves is to prevent a spill in event of damage to the service line, and as redundant protection against backflow.

Bronze swing check valves have been successfully used, but do not close drip tight. Resilient seats improve the closing characteristics, but such valves are equipped with rotating disks that have a bolt protruding through the disk. The bolt tends to gather stringy material. A clear waterway is preferred.

Wye-pattern swing checks are preferred over tee-pattern valves when installed horizontally (due to the gravity component provided) but can be used in either the horizontal or vertical mounting position.

PVC swing checks using neoprene flappers have performed well. These tend to have large, clear waterways and open and close easily without becoming stuck by sulfides. However, some brands are cheaply made and quality control varies.

Many ball check valves, especially spring operated ones, have protruding parts that catch stringy material. Other designs have clear openings and are suitable.

Proven experience with the valve is desired. This can usually be provided when the valve is part of a package provided by an experienced pressure sewer products manufacturer.

2.4.5.5 Building Sewer Appurtenances

Cleanouts are used on building sewers, located near the home or at the point of demarcation between homeowner maintenance and district maintenance. Typical cleanouts are shown in Chapter 3.

Check valves termed "backwater valves" are made to be installed on building sewers, but are rarely used. These are swing check valves with the working parts being removable from the top of the valve, and are available in 7.5-, 10-, and 15-cm (3-, 4-, 6-in) diameter.

2.4.6 Miscellaneous Appurtenances

2.4.6.1 Septic tank effluent screens

While septic tanks are effective at the removal of troublesome solids, they are not 100 percent effective. Some solids are discharged in the effluent. Some effluent pumps have limited ability to handle these occasional solids, making necessary the use of effluent screens or filters, especially at particular installations where maintenance history shows that solids carryover is common. Water well pumps have no solids handling ability so must always be used with a screen. If discharge is made to an on-site disposal system having distribution laterals with small orifices, effluent screening is sometimes suggested to reduce the possibility of orifice clogging.

Basket strainers were fitted to the discharge of a number of septic tanks used on STEP systems in the early 1970s in Florida,[24] and later in Oregon. These were observed over a period of time and showed that solids carryover varied greatly from home to home. Strainers at most installations were found to be nearly free of solids after months of use while those at certain other homes were full and overflowing.

The principal reason for the differences in solids carryover seems to be the practices of the user with respect to disposal of troublesome items. Some solids are prone to carryover as they attain a neutral buoyancy, and are not removed by sedimentation or flotation. Other solids are susceptible to being gas-lifted from the sludge layer and entrained in the tank effluent.

The proximity of the scum or sludge layer to the septic tank outlet is a major factor relating to solids carryover. Scum and sludge accumulation can vary considerably. While the clear space between the top of the sludge and the bottom of the scum layer may be within an expected range, either scum or sludge may constitute a large fraction of the total volume such that one of the two can encroach unpredictably on the outlet.

Another common reason for solids carryover has been that the "pump off" liquid level sensor has been set too near the level of the inlet ports, allowing submerged scum to be drawn into the pump vault. Also common is siphoning that can occur through the pump and discharge piping if the hydraulic grade line of the main is below the liquid level in the septic tank. This lowers the scum layer sufficiently that scum discharges from the tank as effluent.

In cases where scum is carried over, pumps and screens (if used) can be clogged.

To describe the volume and composition of carried over solids, guidance can be taken from the Manila, California STEP system. All flow from this system serving 350 homes is discharged to a main pumping station, fitted with basket strainers having about 6-mm (1/4-in) diameter holes. Annually, about 1,640 cm^3 (100 cu in) of solids/home are captured by the strainers. The solids are comprised of cigarette filters, hair, prophylactics, tiny grease balls, clumps of detergent, common earthworms, plastic sandwich wrap, and lint. Some carryover of scum is suspected at this project for the reasons outlined above.

The recognition that some solids pass through septic tanks and the use of effluent screens is not new. Winneberger showed that 6-mm (1/4-in) mesh screens were recommended by the U.S. Public Health Service in 1920.[24]

Screened pump intakes have been tried, mostly without success. The poor performance has been due to the small screen area, the resulting high velocity through the screens which tends to hold solids on the screens. Their horizontal position permits trapping of floatable material. Also, since the floor of the pump vault is only a few inches below the screened pump intake, solids that fall away from the screen come to rest only a short distance from the screen and are resuspended each time the pump runs, and captured again by the screen. Vertical screens have been more self cleaning.

Effluent screens fall into two basic categories: 1) those that are a part of the septic tank outlet device, and 2) screened pump vaults, located within the septic tank.

Basket strainers are simple devices of the former category, hung on the septic tank outlet, and shown in Figure 2-25. These capture the solids so they can be easily seen for identification and to quantify the volume of carryover. Basket strainers have mostly been used for research rather than for pump protection, since they are not self-cleaning. Manual emptying of basket strainers is periodically required.

A multi-tray filter shown in Figure 2-26 is a patented device that replaces the septic tank outlet tee. It uses stacked plates, separated by a gap of about 1.5 mm (1/16 in) between each plate, and housed within an open-bottomed plastic case. Some solids slough off the filter and fall to the bottom of the septic tank. The plates may be lifted out of the case as a unit and rinsed off to remove solids that may accumulate between the plates.

Slotted PVC well screens have been fitted to septic tank outlet tees as shown in Figure 2-27. The screen can be cleaned with a round swab or brush placed inside the well screen.

The simplest type of screened pump vault is one where mesh is placed over the vault inlet ports, as shown in Figure 2-28. About 6-mm (1/4-in) plastic mesh is usually used. Because of the small screen area, blinding of this type of screen is usually experienced after a year or so, requiring routine cleaning of the mesh which is attempted by hosing the screen from the inside of the vault. Often hair, lint, and other fibrous or stringy material becomes tangled in the mesh and the vault has to be removed from the septic tank for manual cleaning.

The screened vault, a patented method, is shown in Figure 2-29. A large, basket shaped plastic screen of 1.5 mm (1/16 in) mesh fits inside the pump vault but is slightly smaller in diameter, providing an annular space between the vault and the basket. After removing the pump and liquid level controls, the basket can be lifted out for cleaning.

A slotted pump vault is shown in Figure 2-30. A variation of this design not shown is for the vault inlet to be mesh instead of slotted. The slotted vault is made of PVC well screen, usually 30-40 cm (12-16 in) in diameter (depending on the size of the pump and appurtenances). If discharge is to a municipal treatment works, the location of the screen or slots is less critical. Some digested sludge may be pumped in this case, which is to be avoided if discharge is to a drainfield or other facility more sensitive to effluent quality.

In overview of the various designs, proponents of screens that are part of the septic tank outlet tee usually favor the external pump vault arrangement, which better allows factory packaging of pump components. They also prefer that flow through the screen be governed by the natural flow rate through the septic tank rather than coinciding with pumping rates, as with internal vault designs.

Proponents of screened pump vaults internal to the septic tank favor the economy of the internal vault and the integrated packaging of the septic tank and pump vault.

With most screen designs, if the liquid level in the septic tank rises sufficiently, as can happen during a long power outage, the screen can be bypassed from above, carrying scum inside the screen. If the screened vault becomes blinded, the pump vault can be floated out of position due to the higher liquid level outside the vault.

Slotted screens are believed to be more resistant to clogging than mesh screens due to the one-way bridging action provided by the long slot as opposed to the two-way bridging action of the mesh. However, the mesh better insures that long, stringy solids are captured.

The use of screens is vitally important when non-solids handling pumps are used. When effluent pumps are used capable of passing 13-mm (1/2-in) or larger solids, only about one percent of the pumps experience clogging per

Figure 2-25. **Basket strainer used with external pump vault.**

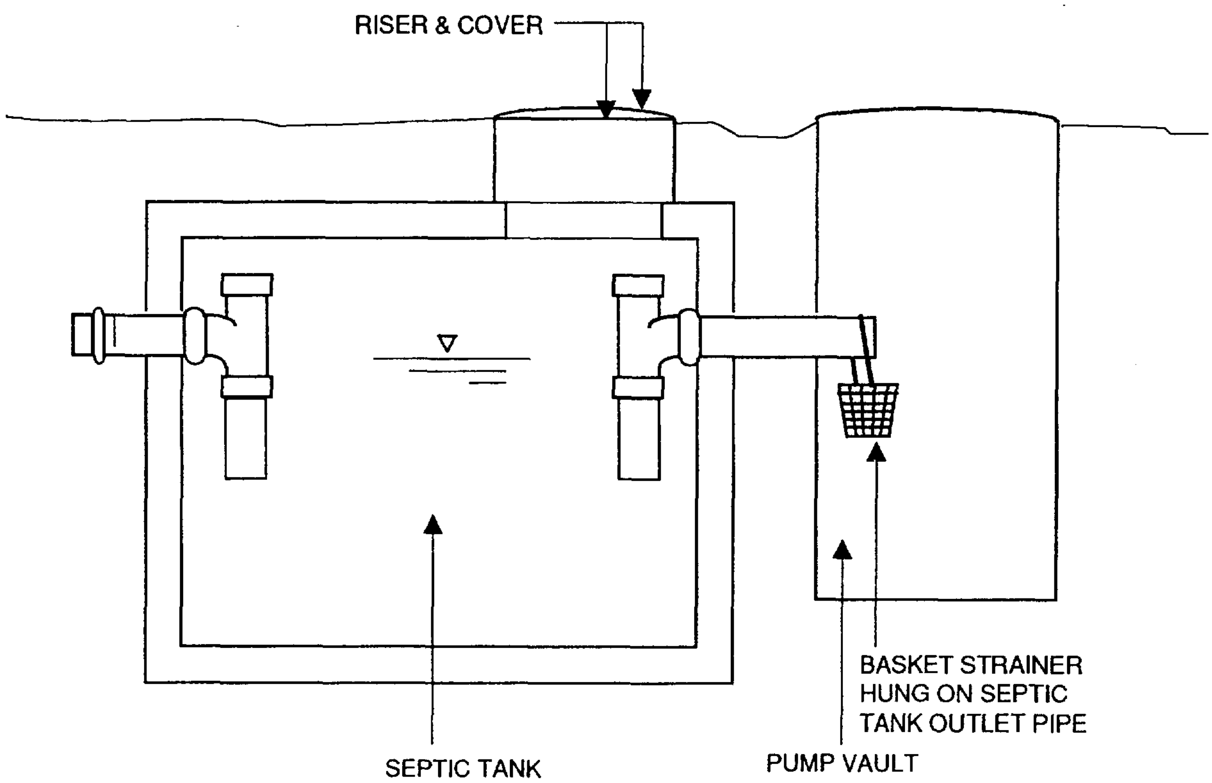


Figure 2-26. **Multi-tray filter, used wih external pump vault.**

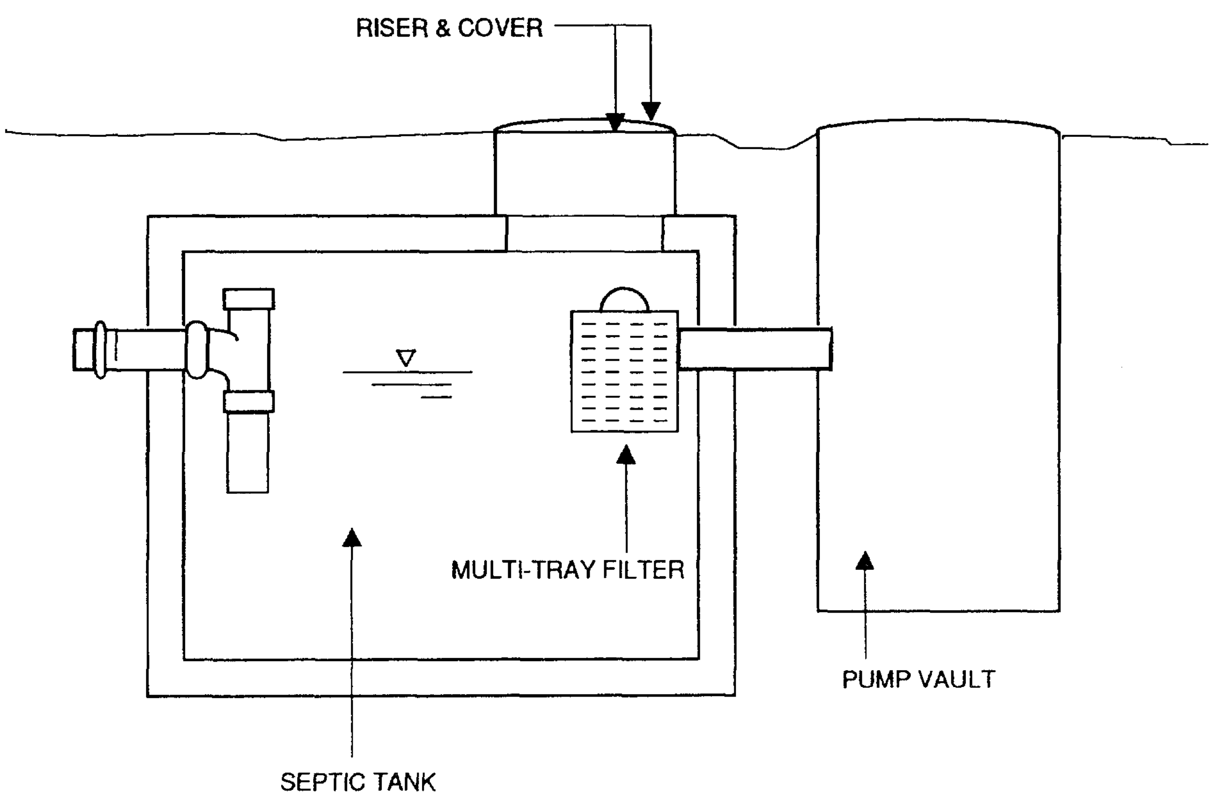


Figure 2-27. **Outlet tee fitted with well screen.**

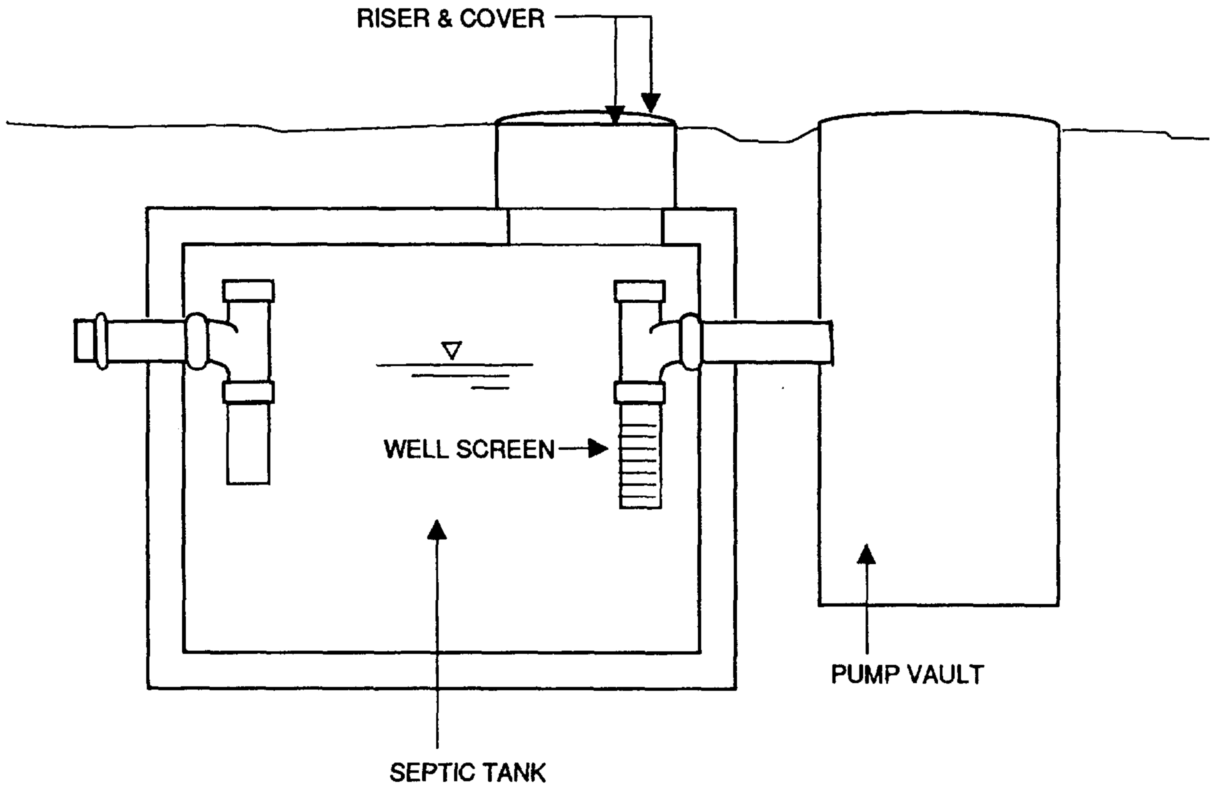


Figure 2-28. **Mesh placed over inlet ports of internal pump vault.**

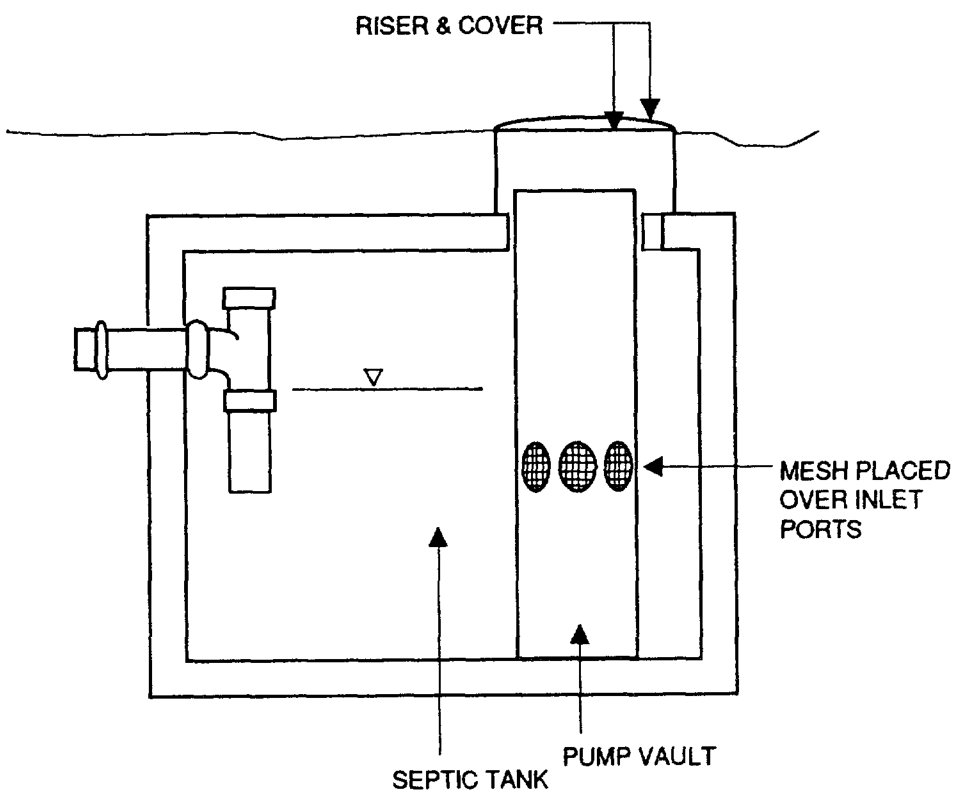


Figure 2-29. **Fully-screened internal pump vault.** (Courtesy Orenco Systems, Inc.)

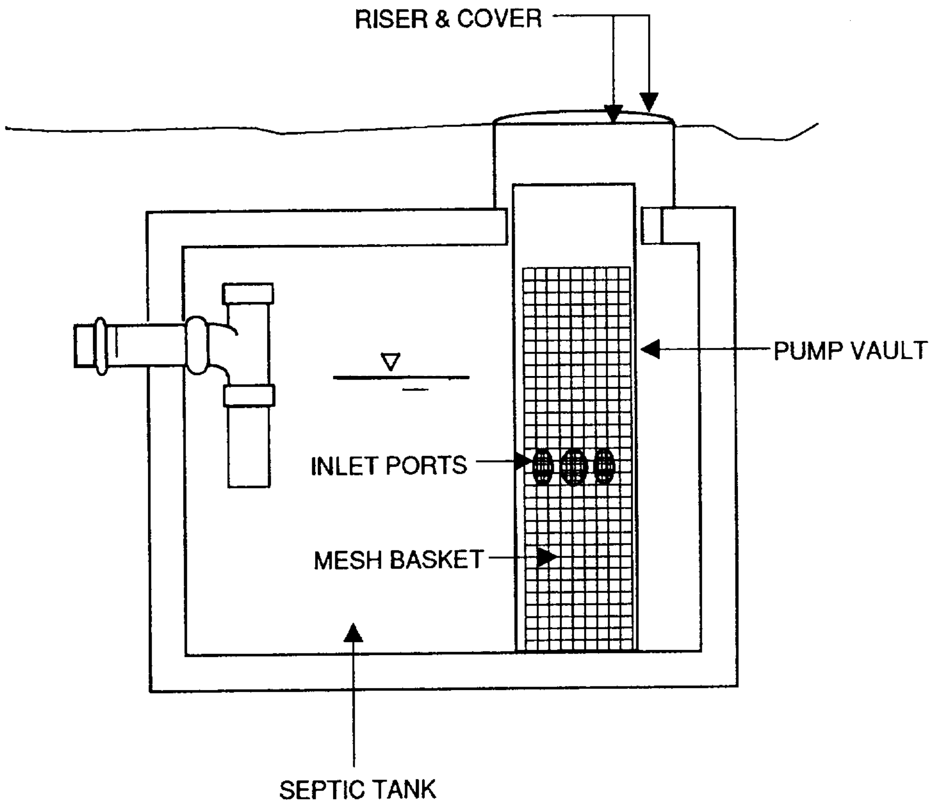
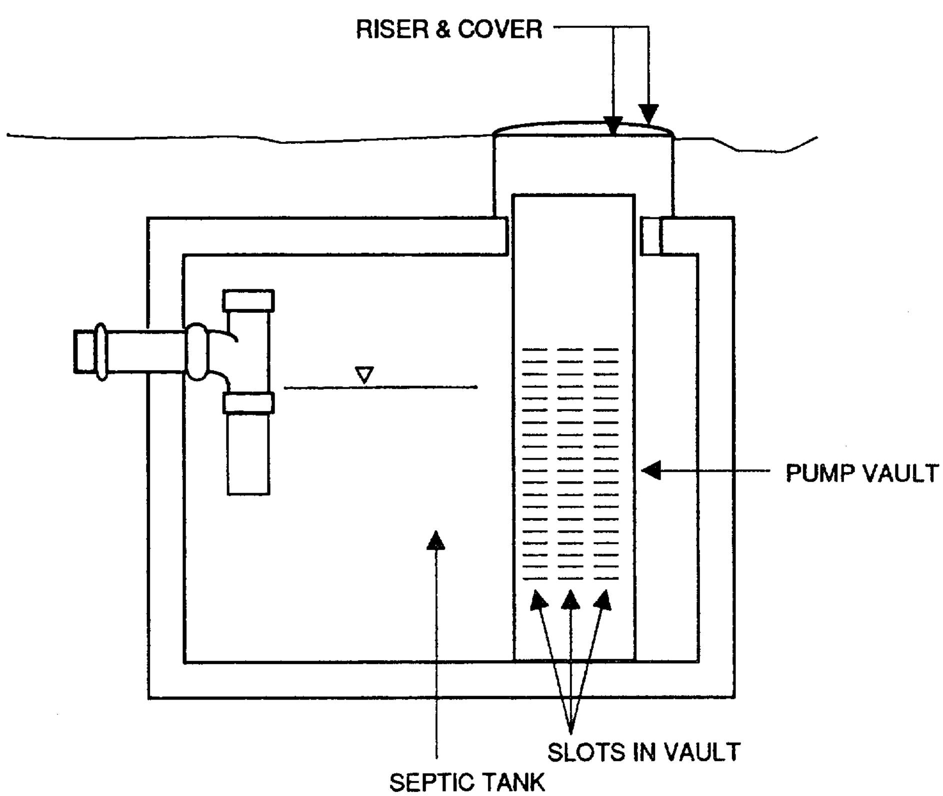


Figure 2-30. **Slotted pump vault.**



year. Accordingly, most installations using effluent pumps do not use screens.

2.4.7 *Odors and Corrosion*

Grinder pump and solids handling pump basins are odorous only to the extent the fresh, raw wastewater is odorous. When the wastewater is retained in the basin for some time it becomes septic and begins producing hydrogen sulfide gas.

On occasions when odor control is required at grinder pump installations, enzymes have been added, either by the homeowner or the maintenance district. The enzymes can also be beneficial in reducing grease accumulation in the pump vault, but are expensive when required for any length of time.

With STEP systems the tank effluent is always septic, and potentially odorous and corrosive. Some of the H_2S can escape from the septic tank, however, and some may be captured by the floating scum layer. The BOD of the effluent is lower than that of raw or ground wastewater. Since sulfide production is generally proportional to BOD, the STEP system effluent has a reduced potential for total H_2S production.

A septic wastewater atmosphere is characterized as being odorous, corrosive, and toxic. The rotten egg odor of H_2S is repulsive and detectable in concentrations as low as 3 ppb H_2S is itself corrosive but is also reactive with *thiobacillus* bacteria present on the appurtenances and walls of the pressure sewer vault above the water line to form sulfuric acid, H_2SO_4. In sufficient concentrations H_2S causes acute poisoning, paralyzing the respiratory center. Methane is also produced by septic wastewater, which is asphyxiating, as is the carbon dioxide and nitrogen present in wastewater gas. When sufficiently ventilated the atmosphere in the pump vault is usually at a safe level for brief exposure.

For odor control, basin covers are typically gasketed or made such that escaping gases are vented into the soil, or ventilation is provided by the roof vent of the home. While H_2S is heavier than air, it is presumed drafted away with the greater volume of air and lighter gases present. So long as turbulence is minimized in the basin to limit the amount of H_2S liberated, odors are rarely reported via roof ventilation. In most cases where problems have been investigated improper house venting has been a major contributor.

Proper materials must be selected for resistance to corrosion. Most packages assembled by manufacturers of pressure sewer components comply reasonably with this requirement. Particularly well-suited materials include Type 316 and Type 304 stainless steel, PVC, polyethylene, ABS, and FRP.

Because of the toxic and asphyxiating atmospheric conditions possible in the vaults, designs should be made where exposure of the service personnel to these gases is unnecessary and difficult. More than brief exposure is to be avoided.

Where grinder pumps or solids handling pumps discharge a short distance, as in a typical service line to a receiving gravity sewer, the residence time in the pipeline is usually short enough for the wastewater to be relatively fresh or even stale, but not so septic as to present a problem of odors or corrosion at the receiving sewer. When they pump to a pressure sewer system where the wastewater is retained in the pipeline for more than about 30 minutes, hydrogen sulfide begins to be produced. With increased retention time the effluent becomes totally septic, with all the attendant concerns.

The septic aspect of the wastewater in the mains presents no particular problem as the PVC pipelines are unaffected. Isolation valves should be made corrosion resistent, as should air release valves. Air releases should vent to an odor control facility, such as a soil absorption bed if much gas is expected to be expelled or if the air release is near habitation.

There have been cases where pressure sewer-collected septic effluent has been discharged to gravity sewer mains without causing nuisance or corrosion. In these cases the pressure sewer flows were small, the receiving sewer flows were large and aerobic, and flows were introduced as quiescently as possible to avoid driving off H_2S. More commonly, however, the discharge is odorous, corrosive, and, in extreme cases, can cause the atmosphere within the receiving sewer to become hazardous.

Concrete sewers are attacked by H_2S. PVC and vitrified clay pipes are inert. The usual situation is that the receiving concrete manhole corrodes more rapidly than any other sewer component due to turbulence during transition.

When discharging a pressure sewer to a receiving conventional sewer, a reach of the latter should be chosen which has a substantial quantity of flow. Some jurisdictions have used a 5:1 ($Q_{receiver}/Q_{pressure\ sewer}$) flow ratio, however such generic rules are not equally applicable for all situations. In cases where pretreatment for sulfide must be provided, aeration is a favored method for converting the sulfide to thiosulfate, but requires a substantial reaction time. Chemicals have been used, such as chlorine, a strong oxidizing agent and bactericide, hydrogen peroxide which is a source of oxygen, and ferrous sulfate which can either act as a catalyst for oxidation of sulfides or precipitate them. All of these chemicals require mixing, and some require substantial reaction times while others react instantly.

Much information is available on the characteristics and pretreatment of septic wastewaters.[29] Unfortunately, information has historically been ignored or poorly understood by the parties involved in design.

Where septic pressure sewer-collected effluent is discharged directly to a municipal treatment facility, odors have not been a problem if the discharge is submerged and diffused, and if the receiving basin is large, well mixed, and aerobic.

2.5 Construction Considerations

2.5.1 Line Changes

Because of the flexibility of small diameter PVC piping and because the pressurized flow regime is not very sensitive to horizontal alignment, minor field changes in alignment usually pose no particular problem and are often made by the construction manager. Major changes should be evaluated and approved by the design engineer prior to implementation. Changes in alignment should be well documented and shown on as-constructed plans.

2.5.2 Grade Control

Profiles are shown on the plans, but in most cases the pressure sewer main is shown to be at a constant depth below ground surface, such as 75 cm (30 in). The profile is necessary for the proper evaluation of air release station use and placement. At culvert crossings, or for separation from water mains or other utilities, the pressure sewer profile may vary from the standard depth. The configuration at these locations must be specified by the designer for air release valve considerations, and by contractors so that the project is properly bidable.

As with horizontal alignment, minor changes in vertical alignment may be made in the field, but major changes should be evaluated in advance by the design engineer. The as-constructed plans should reflect the installed profile.

2.5.3 Service Connections

Grinder pump vaults and septic tanks should be located in an area of stable soil, accessible for construction, but not subject to vehicular traffic. Some GP and SH installations are made in basements.

Some designs locate the vault within a few feet of the home, so wiring can pass directly from the vault to the control panel without need for an electrical junction box in the pump vault. The building sewer is short, reducing maintenance needs and reducing the possibility of receiving infiltration from poorly made pipe joints.

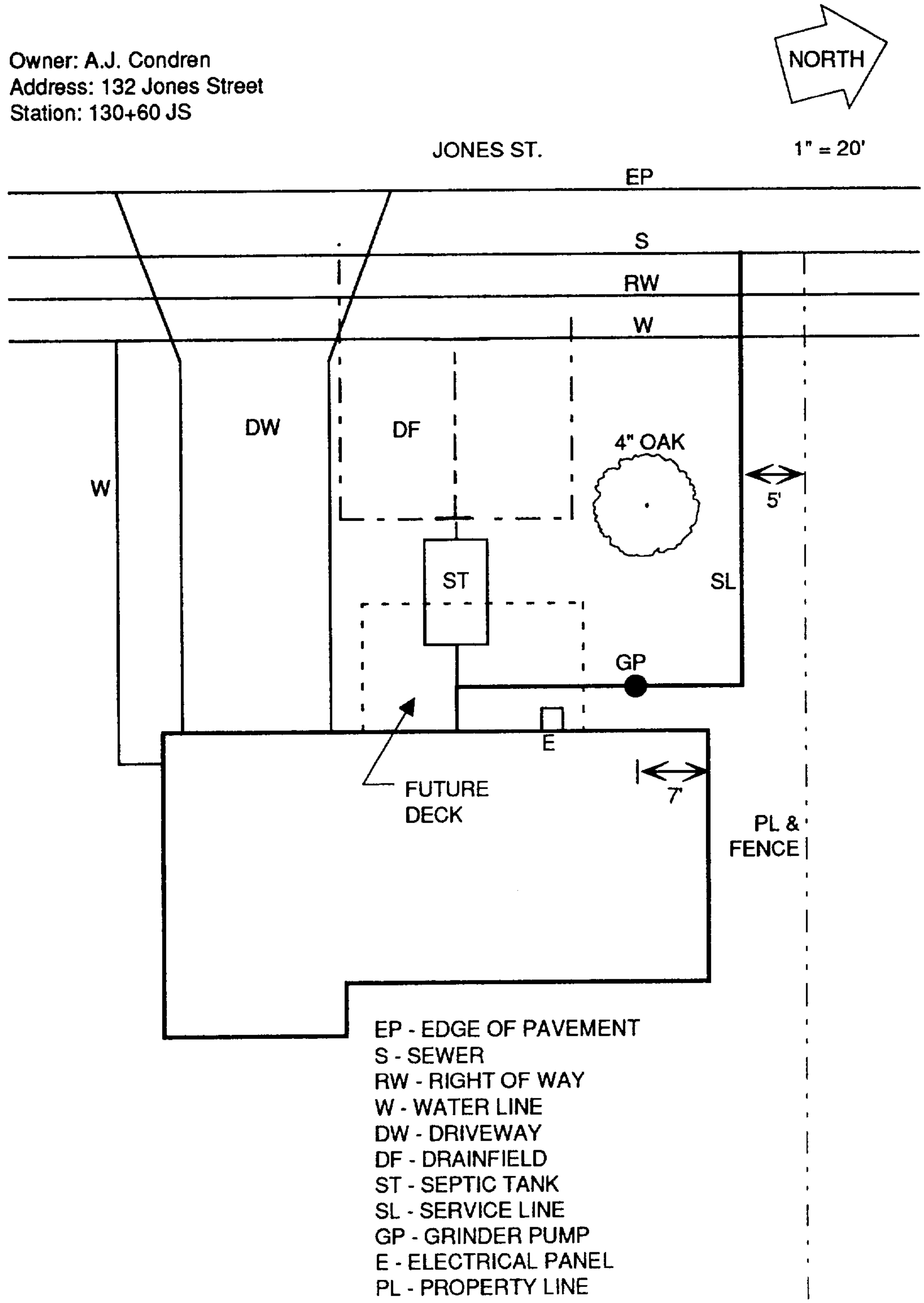
Other designs use long building sewers and place the pumping unit next to the side property line and near the street. This design is uncommon but is used in certain areas, especially where ground slopes are flat and building lots are mounded, thereby providing sufficient downward slope away from the home. The pumping unit is most easily accessed with this design. Where adjacent homes have the pumping units adjoining the same property line, the construction easement from each homeowner is narrower than would otherwise be required.

When serving existing homes the pumping unit is usually located near to the existing septic tank, which terminates the existing building sewer. Being close to the existing septic tank, excavation material for the new tank can be conveniently placed as backfill inside the hole left by the old tank, crushed in place. Usually, old septic tanks are abandoned by being crushed in place or backfilled with sand or gravel. Occasionally the old tank is removed. The new tank may occupy the same location as the old tank. On the rare occasions when existing tanks are considered useable, they must be extensively tested for leaks and illegal inflow sources. These procedures are usually considered too expensive, and contribute to the usual 100 percent replacement approach.

When serving existing homes, planning tank and service line locations must be done with the homeowner's involvement. It is common for the appropriate site for the tank to conflict with the homeowner's wishes to build a driveway, deck, garage, or additional bedroom. The homeowner may know the locations of such features as water wells or buried utilities, which are to be avoided. The family pet burial ground can be a sacred area to be avoided at all costs.

Whenever possible, lot facility plans should be drawn when serving existing homes. These larger scale plans show sensitive areas, and show the locations of the planned improvements. They also list such information as the homeowner's name, phone number, contact person (if the owner is non-resident), whether the resident works nights (day sleeper), if the dog bites, and numerous other points of valuable information. A simple lot facility plan is shown as Figure 2-31. The additional information, usually on the reverse side of the lot facility plan, is:

Figure 2-31. **Example lot facility plan.**



Owner: A.J. Condren
Address: PO Box 1190, Fairbanks, AK 99543
Station: 130+60 JS
Phone: (503)345-3001
Contact person: Joe Baily (renter - resident)
Phone: home 543-4640, work 543-5569
Locations of GP & SL approved by owner? Yes
Easement signed and recorded? Yes

Special notes:
1. Renter (Joe Baily) has been designated to make local decisions on behalf of the owner.
2. Baily is not available Saturdays.
3. Do not trench near roots of 4" Oak tree.
4. Mount electrical control panel 1' higher than normal to account for access from future deck.
5. Replace building sewer to the house foundation. (Existing building sewer has root intrusions and is known to be broken.)

Lot facility plans should be prepared in advance of construction, so the time consuming contacts can be completed. Also, having lot facility plans at the time of construction bidding enables the contractor to better estimate costs and, later, to schedule work.

As locations for the tanks, service lines and electrical service are decided in the field, and agreed to by the involved parties, conspicuous lath may be placed. These mark the agreed location for file photos and remind the homeowner of their locations. Owing to long delays prior to construction the markings may require replacement before construction to jog homeowners regarding these locations. It is common for the homeowner to phone the district a few days later to say they have realized (reminded by the lath) that the routes are unacceptable for whatever reason. While the changes may be costly annoyances, they are preferable to making errors and subsequent changes after the installation has begun, and provide an opportunity for better public relations.

The contractor, sometimes together with the construction manager, should contact the homeowner or resident again a few days in advance of construction. This helps minimize inconvenience, better coordinates the work, and is generally required public relations. The authority must designate a coordinator to ensure minimal disruptions to the homeowners.

Videotapes of the property before and after construction eliminate many disagreements about property damage during construction.

2.5.4 Equipment Substitutions

It sometimes happens that the contractor awarded the job will place orders for equipment that does not comply with the specifications, and not notify the engineer or owner of this. The substitution may not be discovered until the equipment arrives, usually after a considerable time has passed and the construction season is growing short. Claims are made that the equipment is equal to that specified. The client and engineer are sometimes pressured into accepting what they believe is substandard equipment.

To avoid this situation some system owners have opted to purchase key equipment separately, and to furnish the equipment to the contractor. This not only insures that the specified equipment will be used but may have an added benefit of lower cost. However, since the contractor is not in control of that equipment supply there may be concerns for delay if the equipment does not arrive on schedule. The contractor may also take the position that proper operation is beyond the contractor's control. This can be partially avoided if contractors are aware of the owner's plans prior to bidding.

In some cases where the construction contractor provides the equipment, a list of the particular equipment is required to be furnished as a part of the bid, or formal submittals are required. In other cases, only preapproved equipment is allowed, with the list being acknowledged in writing by the contractor. The construction manager is furnished with copies of equipment orders.

Where substitutions are allowed, the securing of samples is advised. If the equipment substituted is a component part of a larger assembly, a prototype of the assembly should be required for examination and testing. This provision should be a part of the contract specifications.

Not all substitutions are detrimental. In some cases the suppliers offer substitutions based on substantial experience, and their suggestions should be heeded.

2.5.5 Testing

Mains should be hydrostatically pressure-tested following established procedures, such as those of the American Water Works Association. Test pressures should be at or near the working stress rating for the pipe materials. Properly accomplished installations can easily pass these tests. If the installation is flawed, that should be known during construction rather than later during operation when the mains are filled with wastewater. The mains may be subject to pressures considerably higher than design during pipeline cleaning operations.

When custom (non-commercial) pumping units are used, prototypes should be built for examination and testing.

Experience has shown that many septic tanks used on STEP systems leak, allowing infiltration. Some plastic tanks deform badly due to backfill loads. Septic tanks should be thoroughly tested and/or be otherwise proven. Concrete tanks are often tested by filling with water to the soffit of the tank and observing seeping and water levels over a period of time. Fiberglass and polyethylene septic tanks may also be hydrostatically tested, and may be further tested by imposing a vacuum in the tank to simulate backfill loading pressures.

2.5.6 Scheduling/Warrantees

Depending on the method and timing of construction, some components can be installed very early during construction, and some very late. There have been some cases where the 1-year equipment warranty period had expired for some of the installations before the facility had initiated operation and the pump had ever been used. The contract documents need to be explicit in stating precisely when the warranty period starts.

2.6 O&M Considerations

2.6.1 O&M Manual

Many pressure sewer systems operate without an O&M manual. Other systems have O&M manuals that resemble design manuals. Neither practice has proven satisfactory. The O&M manual should primarily be a reference document, intended for the regular use of the service personnel.

Major manufacturers of pressure sewer equipment have manuals or catalogs available for the components or packages supplied by them. Some of the information is generally suitable for insertion into the overall manual. For example, air release valve manufacturers can provide cutaway drawings that are beneficial to understanding how the valve works, and details listing and identifying the various parts used. Some septic tank manufacturers have complete O&M manuals describing, for example, how and when septage should be removed.

A "system analysis plan" is particularly useful. This plan capsulates the project on one or two sheets, showing infrastructure pipe routes and sizes, valve locations, profiles, nodes of the accumulated number of EDUs contributing to each reach, and static and dynamic hydraulic grade lines.

Septic sewer gases are expected at STEP septic tanks, at relatively inactive GP vaults, and points where pressure sewers discharge. The proper practices of pressure sewer maintenance are usually such that the gases are not hazardous due to dilution with ambient air, but service personnel need to be aware of the potential hazards of these gases. For example, hydrogen sulfide is known to deaden a persons ability to smell it after brief exposure. This may cause the person to wrongly think the gas has drifted away. Many deaths have been attributed to exposure to septic sewer gases.

Service personnel should be advised of procedures and precautions regarding exposure. Designs should be such that no exposure is required, or at the most, only brief and limited exposure to a diluted atmosphere.

Extensive electricals are used at each pumping unit, typically including an electrical control panel, mercury float switches, and electrical junction boxes. Service personnel are exposed to the possibility of electrical burn or shock in their maintenance duties. They may be standing on wet ground while servicing electricals, and working under adverse conditions such as darkness, rain or snow. Electrical safety should be included in the O&M manual. Designs should limit exposure of O&M personnel to live electrical systems.

Sanitation practices should also be covered in the design manual as with any project involving contact with wastewater.

Simple, straightforward designs are more easily understood and better maintained. Maintenance functions and management programs should be fully considered during the design phase.

2.6.2 Staffing Requirements

Staffing requirements are dependent on the type of pressure sewer involved, the features provided, and the quality of the system. For example, some systems use heavy pumps that require two people to lift them from the vault, while others use light-weight pumps easily lifted by one person.

Some designs have a large reserve volume available in the tank for storage after the high level alarm sounds, or an overflow to a standby drainfield. These are "fail soft" provisions that allow the service personnel to better schedule their activities, while not significantly inconveniencing the user. In contrast, some systems use small basins that hold only a few gallons beyond the alarm level. These systems need to be attended as soon as an alarm condition is known, sometimes late at night or on holidays or weekends.

Quality designed and constructed systems, and those systems receiving regular preventive maintenance generally experience fewer service calls in response to alarms.

Service calls likely to require exposure to dangerous conditions, e.g., live electrical or sewer gas exposure, should be attended by at least two people for safety purposes.

Nearly all systems have defects that are not discovered during construction. If the correction of these defects is assigned to the maintenance forces, excessive maintenance can result. A preferable alternative is to identify the defects, and to correct them as a capital improvement.

Recognizing all of the variables involved that cause some systems to be more maintenance intensive than others, no general rule can be made regarding staffing needs. However, systems that are well designed, well built, and properly maintained may experience a mean time between service calls (MTBSC) of about 4-years, loosely meaning that 1/4 of the pumping units will be serviced in a year.

The personnel-hours spent per service call depends on whether two personnel are required or one, and the nature of service typical of the particular system. The mean times range from 20 minutes per service call to about 3 hours.

A minimum of two personnel are required to be trained and available. On some systems one person can attend to the service calls, but a fully trained and experienced backup is needed for times when the lead person is unavailable. The two people do not necessarily have to be full time employees, but at least one person has to be available on call.

In the most general sense, two full time employees have usually been found sufficient to maintain a well-designed system of about 1,000 pumping units.

2.6.3 Operator Training

Typically, the malfunctions of most service calls are electrically related. The service personnel should be trained accordingly and should have the appropriate credentials.

Familiarity and a basic knowledge of plumbing practices, particularly as applied to pumping, is required. Personnel should be advised on practices regarding exposure to septic sewer gases. Public relations are important. Service personnel should be able to represent the sewer district diplomatically. Training in this subject area may be advised.

2.6.4 Spare Parts Inventory

The number of spare parts required is related to the particular system being operated and maintained.

In general, sufficient pipeline fittings and special tools should be on hand to quickly repair any rupture that may occur in the piping system. Anticipation of need during non-working hours should be made, when parts would not be available from outside sources.

All working parts of the pumping units, for example the pump itself, liquid level sensors, check valves, and control panels should be on hand in sufficient quantity to quickly restore operation in event of malfunction. The need for inventory can be refined by experience with the particular system, with consideration given for particular parts that cannot be obtained quickly. In general, an inventory of 5 percent of the number of pumps in operation is sufficient.

Many pressure sewer systems are intended for growth within the system, and for piping extensions to be made. These systems usually have enough parts and equipment on hand to satisfy maintenance needs.

2.6.5 As-Built Drawings/Maps

The prevention of damage to pressure sewer mains and service laterals caused by subsequent excavations should be a high priority.

Warning signs have been posted on some projects, periodically placed along the route to notify or remind excavators of the presence of the pipeline. Toning cable is installed adjacent to the pipeline on some systems, which can be induced with a tone and located using standard utility-locator devices. Identification tape buried with the pipelines further warn excavators. And reliable as-built drawings are beneficial, especially to those agencies planning future excavations.

As-constructed lot facility plans, showing locations of the pumping unit, electrical service, service line and building sewer are equally helpful. These are of particular benefit when new service personnel are engaged who are unfamiliar with the locations of key site features.

2.6.6 Maintenance

2.6.6.1 Normal

Service calls made in response to phone calls by the home residents constitute most maintenance activities.

The amount and type of maintenance required varies widely between projects, depending on the equipment

Table 2-6. **Distribution of Causes for Call-Out Maintenance On Selected Grinder Pump Pressure Sewer Projects**

Category	Percent of Occurrences
Electrically related	25 - 40
Pump related	20 - 25
Miscellaneous	20 - 30
Pump vault related	5 - 15
Piping related	5 - 15

used, quality of installation, and other natural and human factors.

a. Grinder Pump Maintenance

To describe maintenance functions generally, Table 2-6 was prepared based on the experiences of two major projects, one using centrifugal pumps and the other using progressing cavity pumps. Each project kept detailed daily records of service calls. A tedious examination of the maintenance records was made, augmented by detailed personal examinations of the projects and visits with the maintenance staff.

Causes for maintenance were divided as follows:

Electrically related: Where mercury float switches were used, about 50 percent of the service calls related to their malfunction. Grease accumulation was the principal cause of the float switches not operating properly. The typical correction was removal of the grease, adding enzymes to the pump vault, and providing extra enzymes to the home resident along with the request that they dispose of cooking grease elsewhere. Other descriptions of malfunctions included the float switches being obstructed, loose, cracked, stiff cords restricting movement of the float, and simply "not working".

Where pressure switches were used in lieu of float switches, about 20 percent of the electrically caused service calls related to them. Adjustment or replacement of the switch was usually accomplished.

Problems with electrical control panels were highly diverse, ranging from inoperative components to loose wiring, and problems with the intrusion of ants or other insects. Control panel problems constituted 25-55 percent of the electrically related causes for service calls.

Fuses were blown or circuit breakers were tripped or turned off in 7-18 percent of the electrically related service calls. The reporting was not clear as to whether the breakers were tripped out due to an overload or ground fault, or turned off by the homeowner.

Problems with splices contained in electrical junction boxes can be a major cause of maintenance, especially if the splices in the junction boxes are not water tight. Junction boxes typically leak, despite claims to the contrary.

In about 3 percent of the electrical problem cases, the homeowner's power supply was at fault.

Other electrical problems too diverse to categorize represent perhaps 5 percent of these service calls.

Pump related: Pumps were often removed and replaced on one project, and seldom removed on the other. On the project where replacement was more common, it was usually due to the pump drawing excessive amperage, indicating that something was jammed in the grinder mechanism. Troublesome materials found in grinders were mentioned in the reports as being washrags, sanitary napkins, underwear, kitty litter, handkerchiefs, and similar items.

Miscellaneous: One system reported overflowing wastewater onto the yard or backups in the home on 60 percent of the miscellaneous service calls. This was to be expected as the pump vaults were small. The other system investigated used emergency overflows to holding tanks, so experienced rare cases where surfacing or piping backups occurred.

Odor problems were reported on one of the systems. Usually the field personnel attributed this to lack of use, causing the vault contents to be septic. Where vents were used in the vault covers, they were checked to see if water was in them preventing the transmission of gases to atmosphere.

Pumps or service lines were sometimes found to be airbound. Check valves were reported to be leaking slightly in only 2 percent of the miscellaneous service calls.

A large fraction of the miscellaneous service calls were too diverse in nature to categorize.

Pump vault related: One project used pump vaults and piping within the vaults that had been designed and produced by a local supplier, rather than that available from the pump manufacturer. Over half of their pump vault related service calls were related to changing this inadequate piping system.

The intrusion of water into the pump vaults was noted on both projects. In some cases the water entrance was due to roof drain discharging in proximity to the pump vault, or due to careless irrigation practices. In many instances the pump vault was placed too low, so water could puddle around and over the vault cover.

Other pump vault related service calls were diverse, ranging from damage inadvertently caused by the home resident to faulty installation during construction.

Piping related: Piping related causes for service calls were similar for both projects. About 50 percent of the calls were for clogged or broken building sewers (usually a maintenance responsibility of the homeowner). Forty percent of the calls related to damaged service lines, and the remainder were diverse.

b. STEP System Maintenance

Two major STEP projects were selected for detailed evaluation, both having kept extensive daily records of service calls. Both systems used submersible centrifugal effluent pumps. Table 2-7 indicates causes for call-out maintenance.

Table 2-7. Distribution of Causes for Call-Out Maintenance on Selected STEP Pressure Sewer Projects

Category	Percent of Occurrences
Electrically related	40 - 60
Pump related	10 - 30
Miscellaneous	20 - 40
Tank related	1 - 5
Piping related	5 - 10

Causes for maintenance were divided as follows:

Electrically related: Both systems used mercury float switches, and both systems also used displacer switches on early installations. The mercury float switches have been the cause of numerous maintenance calls, but less than the displacers. Some of the displacers remain in service on one project and have been particularly maintenance intense due to imperfect design, but not due to problems inherent with the concept. Well over half of all electrically related service calls are attributed to adjustment or failures of the liquid level sensors. The remaining reasons for electrical malfunctions are spread among problems with junction boxes (used on one of the two projects), electrical control panels, and tripped or thrown breakers.

Pump related: One project used low cost pumps, relying on the philosophy that they are relatively easy and inexpensive to replace, while the other project used more expensive pumps. Both approaches have been reasonably successful. The low cost pumps are removed whenever there appears to be a pump related problem. They are taken to the shop for evaluation, and in the majority of cases they are found to be clogged with a cigarette filter or prophylactic. Some of these clogging problems are attributed to an unannounced change made in the design of the pump which made it less able to pass solids than the original design which was evaluated and selected. The clogging object is removed in the shop, and the pump is placed back in service during a subsequent service call.

The project using more expensive pumps encounters clogging on only a trivial number of pumps; about 1 percent of the installations. The need to remove these pumps from the basins is rare.

Miscellaneous: Air bound service lines are a common occurrence on one system, and air bound mains are reported on the other. This is one of the most common sources of maintenance calls.

One system's staff attributes the problem to reaches of the main having so few homes presently served that peak flows are of such short duration that air accumulations are not purged from the main. The other system has reaches experiencing the two-phase flow of air and water. Improved venting practices have successfully corrected problem areas, but have not been applied to the project as a whole.

Tank related: Few tank related service calls occur, but this is because high quality tankage was used on both projects. Tankage problems have been so extreme on some other projects using poor quality tanks that little attempt was made to deal with the problems by maintenance forces. Instead, replacement was undertaken as a capital improvement.

Overflows infrequently occur because of the large reserve volume provided in the septic tank.

Piping related: Clogged building sewers represent half of these service calls, even though maintenance of the building sewer is the responsibility of the home owner. Damaged service lines represent the other half of the service calls.

2.6.6.2 Preventive

Pipeline locating by sewer staff may be frequently needed by utility companies or others planning excavations in the area. Mainline isolation valves should be exercised annually. Air release stations should be checked for proper operation, the frequency being best established by experience with the particular system. If pretreatment devices are used, they need to be attended regularly.

There is little preventive maintenance practical to accomplish at most pumping units. The pumps and ancillary components are not routinely removed from the vaults.

On routine maintenance visits the pumps and controllers are run through their cycles to see that all aspects are in working order. Voltage and amperage readings are taken. High amperage indicates that something is restricting the movement of the rotor, usually a clogged impeller or grinder. Motor starter contacts are sometimes cleaned, especially if the area experiences problems with insect intrusion.

The first year or two after installation, earthwork settlement is common around the pump vaults and may need to be corrected. Often the tank settles, causing the top of the vault to be below ground surface where inflow could enter. The tanks then require a water-tight extension to be retrofitted.

Mostly, routine maintenance consists of visual inspection. Grinder pump vaults (particularly with float switches) are washed down to reduce grease buildup. Where enzymes are popular, they may be added. STEP pump vaults accumulate less grease, so there is less need to clean them. The sludge and scum accumulation in the STEP tank should be monitored during these visits.

2.6.6.3 Emergency

Even though they may be infrequent, mainline ruptures are possible. Repair materials and equipment should be reasonably accessible for such needs.

When pump vaults are used that have small reserve volumes between the high level alarm setpoint and the top of the basin, response time must be prompt or an overflow or backup in the home will occur. Either way, the user is inconvenienced. In many cases, maintenance forces respond to such calls whenever the call is received, even during late night or early morning hours.

During extended power outages pump basins may be filled and overflowing or backing up in the home. However, water use and corresponding wastewater flows are greatly reduced during power outages. An emergency overflow or the provision of adequate reserve space is a "fail soft" provision. Portable standby generators and gasoline-powered pumps have been provided in a few cases, but rarely if ever used.

2.6.7 Record Keeping

The O&M manual should contain forms for this purpose. A record should be kept of routine maintenance, along with a summary list of corrective action to be taken. A data base should be prepared to document call-out maintenance. With a data base, a printout of previous maintenance for any particular address can be prepared for the service person attending a call. This is especially beneficial to new employees, to alert them as to probable causes of the malfunction. Repeat calls to particular addresses for repetitive problems are common. These are clearly shown by data base reporting.

2.6.8 Troubleshooting

About all the field personnel usually know about the performance of a pressure sewer main is that it is adequate.

As growth occurs an increased frequency of high level alarms at the individual pumping units is usually due to the mains having reached capacity or having developed a problem with air-caused headloss.

A preferable method to measure the performance of the mains is to take readings at pressure monitoring stations located at key locations along the route of the main. These are taken periodically, and compared with previous readings that correspond to times when lower populations were being served, periods of especially high or low infiltration, periods when air accumulations in the mains may be expected, and other critical times. In that way the hydraulic performance of the system is measured and documented. Air binding conditions can be identified, located, and corrected. Knowledge of the capacity and other characteristics of the system is continually refined.

During service calls for the pumping units, the service personnel usually attempt to troubleshoot the problem and correct it in the field. A typical scenario is as follows:

First, they confirm that power is being supplied to the control panel and observe the liquid level in the tank to confirm that a high water condition exists. If no reserve volume remains available to receive flow, they may pump the basin down some by running the pump manually (if it will run), or by using a mobile pump.

Then, they may turn the power off so they can work more safely with the malfunctioning installation. Guided by their experience with pumping units on the project, or a history of performance of the particular pumping unit being serviced, they first address the most likely causes of the problem. A common first check is of the mercury float switches, often obstructed by grease or otherwise being out of position.

They will run the pump on the manual switch setting in the electrical control panel, and take amperage readings. A high-amperage reading usually indicates a jammed impeller. A low amperage reading usually indicates an air-bound pump.

By this process the cause of the malfunction is identified and corrected in the field. Not infrequently, a repair is made that is believed to have been the cause of the malfunction, only to receive another call for service the next day. In some cases components are taken to the shop for further evaluation.

2.7 System Costs

2.7.1 Construction

2.7.1.1 General

A wide variety of factors cause construction costs to vary considerably from project to project.

Topographical matters, such as the steepness or flatness of an area can impact costs. The proximity and number of culvert or buried utility crossings can greatly influence the cost of pipeline installations. Geological issues such as rock excavation, fragile soils, or high groundwater conditions are major considerations in preparing cost estimates.

Prices also vary with geographical setting, typically being higher in northern metropolitan areas, for example, than in the rural south.

The attitude of the public to be served is important. Consider, for example, the reluctance a contractor would have to enter private property for installation of pressure sewer on-lot facilities if the property owners were opposed to the project. Unit bid prices may reflect the attitudes of the public, particularly with area contractors.

The burial depth of pipelines, compaction requirements, restoration required, degree of field inspection, and traffic control are other examples of causes for cost variance. Due to economy of scale, large projects usually experience lower unit prices, but this may be tied to the bidding climate and the availability of contracting companies large enough to bid the job.

Familiarity with pressure sewer installation plays an important role. It has been common for the first projects built in an area to experience higher unit prices than subsequent projects due to uncertainties of the contractor. For this reason some engineers have arranged for interested contractors to make a few installations on a time and materials compensation basis prior to the time of bidding. This allows the contractors to sharpen their understanding of the project requirements, and to refine estimates. It also better acquaints the contractors with the engineers, demonstrates installations to the client and the public, and frequently results in final design revisions.

Funding and regulatory requirements play a part in project cost estimating to the extent that the regulations may be a help or hindrance to the contractor, the client, and the engineer.

Because of the many variables, accurate cost estimating guidelines are beyond the scope of this manual, but some generalities are given.

2.7.1.2 Piping systems

Piping systems are best estimated using guidance from water system projects built in the same area, if similar materials and specifications are used. The best situation is one where the water line project was designed and construction managed by the same engineering firm producing the sewer cost estimate. In this way, project similarities and differences can be factored into the comparison from intimate familiarity. If the estimating engineers are not familiar with the project they are obtaining guidance from, they should become familiar with the specifications for that project to rationalize differences between the projects. In some cases, the Associated General Contractors (AGC) can provide helpful insight.

The prices for piping materials can usually be obtained through local suppliers. PVC is generally priced by the pound. At present (mid 1991), in large quantities, a cost of $1.30/kg ($0.60/lb) can be used, but this may fluctuate considerably. PVC weighs about 1,425 kg/m^3 (89 lb/cu ft).

In the absence of better information, Table 2-8 provides estimating data for planning purposes only. This table was prepared by reviewing bid tabulations from numerous projects throughout the United States. Some projects were known to have been built so cheaply that long term performance was questionable. Other projects had unusually stringent specifications or other features that resulted in particularly high costs. Both the high cost and low cost bid tabulations were discarded, leaving mid range averages to produce this table.

Pipe prices include furnishing and installing the pipe, excavation, bedding, backfilling, compaction, pressure testing, cleanup, and related requirements. Not included

Table 2-8. **Average Installed Unit Costs (mid-1991) for Pressure Sewer Mains and Appurtenances**

Item	Unit Cost ($)
2-in Mains	7.50/LF
3-in Mains	8.00/LF
4-in Mains	9.00/LF
6-in Mains	11.00/LF
8-in Mains	14.00/LF
Extra for mains in A.C. pavement	5.00/LF
2-in Isolation valves	250/each
3-in Isolation valves	275/each
4-in Isolation valves	350/each
6-in Isolation valves	400/each
8-in Isolation valves	575/each
Automatic air release stations	1,500/each

Table 2-9. **Average Unit Costs (mid-1991) for Grinder Pump Services and Appurtenances**

Item	Unit Cost ($)
2-hp centrifugal grinder pump	
- List price	1,200/each
- Quantity price	600/each
Simplex GP package	
- List price with 30-in vault	4,100/each
- Quantity price with 30-in vault	1,800/each
- Installation	500 - 1,500/each
4-in building sewer	16/LF
1.25-in service line	6/LF
Abandon septic tank	400/each

are allowances for such items as rock excavation, engineering, and administration.

2.7.1.3 Grinder Pump Services

As shown in Table 2-9, a typical list price for a 2-hp pump is presently about $1,200. The list price for a simplex grinder pump package is about $4,100. This example package includes the following. (The package would differ if a progressing cavity type pump were supplied, e.g. the pump would likely be rated at 1 horsepower, and liquid levels would be sensed using a trapped air system. However, costs should be similar.)

- Pump - 2 hp
- Pump vault - 30-in diameter x 8-ft deep
- Pump vault cover
- Slide-away rail assembly
- Piping within vault, with gate valve and check valve
- Electrical junction box with cord grips
- Mercury float liquid level sensors
- Electrical control panel, including:
- NEMA 3R enclosure
  - Circuit breaker
  - Capacitors
  - Motor start contactor
  - Hand-off - auto switch
  - Audible and visual alarm
  - Audible alarm silence with auto reset

When provided in quantity, prices are considerably reduced. Typical volume prices are about $600 for the pump alone, and $1,400 for the pump package using a 60-cm (24-in) diameter pump vault, or $1,800 for a pump package using a 75-cm (30-in) vault.

Some dealers specialize in providing GP packages at low prices, a typical price being about $1,300. However, many of the components are not provided by the pump manufacturer, but are instead purchased by the dealer from a variety of sources. The dealer often assembles some of the parts. The assembly may or may not have been field-tested and refined.

A low-cost, dealer-provided package usually differs from the factory package in several ways. The pump vault is typically smaller, usually 60-cm (24-in) diameter x 1.5-m (5 ft) deep, and is made of thin wall FRP. Hose is used for the discharge piping instead of hard piping, or galvanized metal piping may be used. No slide away, quick-disconnect coupling is provided. The pump rests on feet screwed into the bottom of the pump instead of being suspended as most factory packages are made. No electrical junction box is provided, i.e., wiring is routed directly from the pump vault to the control panel without splicing. The electrical control panel is often made simpler and with lower cost components. A visual alarm is provided instead of audible and visual, which also eliminates the need for audible alarm automatic reset circuitry.

Some dealer-provided packages may be quite good, but the least expensive packages usually compromise quality, pump vault size, and some other features.

In some cases, sewer districts acquire the various parts and pieces, and assemble the packages themselves, including manufacture of the electrical control panel. A savings of about $200/package has been reported by several districts following that practice, with variable results.

Installation costs of GP services vary considerably depending on the standards being met, the degree of restoration required, whether existing or new homes are being served, and a host of other factors.

The lowest cost installations are made by sewer district personnel serving new homes prior to landscaping being done. In these instances, costs as low as $400 have been reported. Contractors' bid prices are usually higher and typically are $500-1,500.

From the above, the total furnished and installed cost of simplex GP services ranges from $1,800 to over $4,000, not including building sewer replacement, abandonment of the old septic tank (if applicable), and service line installation.

When serving existing homes, the building sewer is often replaced to limit I/I. For economic reasons GP vaults are sometimes placed only a few feet from the home which limits the amount of building sewer required and the length of wiring needed.

"Abandonment" of the old septic tank is usually required by the authorities, which means removing and properly disposing of the septage, then either filling the septic tank with sand or crushing it in place and backfilling the hole.

2.7.1.4 STEP Services

Prices of effluent pumps vary according to the quality provided. For examples of the varying qualities, some pumps use ball bearings while others use sleeve bearings. Some use Type 316 stainless steel fasteners while others may use a type of stainless steel that is not corrosion-resistant to the STEP effluent. Motor types vary, as do impellers and seals. Some STEP pumps are built for the specific purpose while others are inexpensive sump pumps, used as pressure sewer pumps whether suited or not.

Pump prices also vary according to the head they produce, and consequently vary with the horsepower of the motor required.

The list price for a typical low-head effluent pump of good quality is about $300, while a higher head, high quality pump has a list price of about $800. A factory-provided package, using a pump vault external to the septic tank, has a list price of about $2,500-3,000 depending on the pump supplied. This example package includes the following:

- Pump - 1/3 to 2 hp
- Pump vault - 24-in diameter x 6-ft deep
- Pump vault cover
- Slide-away rail assembly
- Piping within vault, with gate valve and check valve
- Electrical junction box with cord grips
- Mercury float liquid level sensors
- Electrical control panel, including:
  - NEMA 3R enclosure
  - Circuit breaker
  - Motor start contactor
  - Hand-off - auto switch
  - Audible and visual alarm
  - Audible alarm silence with auto reset

The STEP pump vault is smaller than a GP vault because reserve volume is provided in the septic tank.

When provided in quantity, prices are considerably reduced.

STEP packages use a discharge hose assembly more commonly than the slide-away rail assembly and hard piping listed above. Also, they are often provided by a pump dealer rather than the factory. The pump dealer may provide the package as a specialty sideline, or may custom assemble them according to the design and specifications provided by the engineer. The latter service can also be provided by the factory, especially if a quantity order is involved.

A typical price for a dealer-provided STEP package using a pump vault external to the septic tank may vary from $700 to $1,500 depending on the particular pump supplied, the quantity ordered, and other variables. Packages made to be inserted into the septic tank, as contrasted against the external vault design, are generally about $200 less expensive.

A new water-tight septic tank is often required due to infiltration expected to enter the existing septic tank. Water-tight septic tanks vary in cost according to the quality provided, and according to the materials used. Concrete tanks are usually less expensive than well constructed and engineered FRP or polyethylene tanks, but are heavy and more difficult to install in confined spaces. Prices for quality tanks of either material generally are $600-1,000.

Installation costs vary depending on whether new or existing homes are served, the degree of restoration required, if new or existing septic tanks are used, the size of the project, and a host of other factors. Mid range installation costs for retrofitting existing septic tanks have been about $600-1,200, and when installation of a new tank is required, costs are about $1,000-1,500. These costs do not include replacement of building sewers, service line installation, connection to the main, abandonment of the old septic tank, or restoration.

Average, generalized prices for STEP equipment and installations are shown in Table 2-10. Price extremes

Table 2-10. Average Unit Costs (mid-1991) for STEP Services and Appurtenances

Item	Unit Cost ($)
Effluent pump list price	300 - 800/each
Effluent pump quantity price	200 - 500/each
Simplex factory package list price	2,500 - 3,000/each
Quantity package price w/external vault	700 - 1,500/each
Quantity package price w/internal vault	600 - 1,200/each
New septic tank	600 - 1,000/each
Installation (retrofit of existing tank)	600 - 1,200/each
Installation (with new septic tank)	1,000 - 1,500/each
4-in building sewer	14 - 18/LF
1.25-in service line	4 - 8 /LF
Abandon septic tank	300 - 500/each

extend far beyond the ranges given here, but are not indicative of general prices for typical well-built projects.

2.7.2 Operation and Maintenance

The operation and maintenance cost for pressure sewers varies greatly, depending on system size and quality. In some instances pipelines have been laid with lax specifications and little inspection. The subsequent maintenance required and lower level of reliability probably offsets the initial cost savings.

The maintainability of the on-lot facilities plays an important part in determining the cost of long term maintenance. For example, some systems are difficult to maintain in that removal of the pump, liquid level controls, and electricals are difficult and unpleasant tasks. In such cases, when a service call is occasioned the service personnel tend to only patch the problem with the result that the number of service calls received increases over time. Preferred for long-term economy are designs where the working parts are easily tested, repaired, and if possible, shop or factory reconditioned.

Many systems have inadequate cost accounting systems, making O&M cost analyses difficult to accomplish or misleading. Also, systems vary widely as to type. Some are grinder pump systems while others are STEP systems. Some systems have their own treatment facilities to operate and maintain, while others discharge to nearby facilities in other jurisdictions. In some cases maintenance is provided by contractors, and in other instances maintenance is provided by the controlling agency's staff who may have part time duties other than maintenance of the pressure sewer.

As a result, a detailed analysis of particular project circumstances is required to forecast O&M cost.[30] With that caveat, O&M costs are reported here for one system.

The Glide, Oregon pressure sewer involves about 20 miles of main. A total of 680 EDUs are served by 420 STEP installations, 12 GP units, and 10 variable grade gravity sewer connections. The setting is primarily residential but several schools are served, several restaurants, mobile home parks, and similar installations. The system has been in service since the late 1970s (over 10-years).

Glide is a quality system that was built to demanding standards, and closely inspected. All main installations were specially bedded and backfilled, and pressure-tested. Heavy-duty pumps were used.

Two full-time field personnel maintain the system. While both attend the collection system, one of the personnel focuses primarily on O&M of the treatment facilities (oxidation ditches and mixed media filtration), while the other persons primary obligation is with the collection system.

A detailed cost accounting system is in place. Typical O&M costs incurred are shown in Table 2-11.

Labor costs reported in Table 2-11 include approximately 50 percent fringe benefits, including FICA, retirement, sick leave, and vacation.

No facility amortization or equipment rental is included, nor is customer billing and accounting.

Given the 680 EDUs served, and the total O&M annual cost of $142,200, or $17.43/month/EDU. Excluding O&M for the wastewater treatment plant, and the WWTP prorated share of the overhead, remaining overhead and O&M of the pressure sewer is $4.77/month/EDU.

2.7.3 User Charges and Assessments

When conventional sewers are used, the front-end construction cost is often high. In comparison, pressure sewers generally have a lower initial cost. When the pressure sewer main has been installed and treatment facilities are on line, service to the nearby properties is available. The higher cost item of the on-lot facilities (pump, etc.) is deferred until service is needed or until the property is built upon. Subsequent users finance the capital cost of their own on-lot facilities as opposed to that being a district obligation.

This encourages innovation and sometimes departure from traditional methods of assessment. The high initial cost of conventional sewers may financially require assessment to be applied to all fronting properties, whereas pressure sewer mains may affordably bypass properties not intended to be served.

Table 2-11. **O&M Cost Accounting Records for the Glide, Oregon Pressure Sewer System ($1,000)**

Item	Overhead	WWTP	Collection	Services	Total
Labor	28.6	56.7	2.3	16.3	103.9
Materials	2.1	24.3	0.6	11.3	38.3
Total	30.7	81.0	2.9	27.6	142.2
%	22	57	2	19	100

Average costs for 1988 and 1989.

An "Association" approach to financing is possible, as opposed to the "District" approach. An association, as described here, obtains revenues from user and connection charges but has no taxation authority.

Pipelines may be sized to serve those properties desiring service (plus some allowance), as opposed to the conventional sewer - district practice of sizing sewers to serve an entire area at 100 percent anticipated development.

As a guideline for future projects, probably little can be learned from the service and connection charges made in communities now served by pressure sewers. This is because the economics vary so widely. Some projects have received substantial grant funding while others received none. Some projects can be constructed economically while others will be expensive. Reasons for the cost variances include the availability of existing treatment facilities, rock excavation, size of project, and other parameters described throughout this manual.

In a review of 5 projects, monthly service charge rates were set to compensate O&M expenses for the services, collection system, treatment, and for management. Monthly rates were $12-20. Connection charges pay for on-lot facility materials. Sometimes installation charges are included, and in other cases they are paid separately by the homeowner.

Also included in the connection charge fee is a prorata share of the piping system infrastructure and treatment facilities. Connection charges were about $2,000-4,000.

Additional information regarding the time value of money associated with the use of pressure sewers is contained in a book by Thrasher.[9] Deferred costs of subsequent pump installations and O&M costs equate to a lower present worth.

2.8 System Management Considerations

2.8.1 Homeowner Responsibilities

During the planning and design phase property owners should become informed about the project and once properly informed, become involved. This is true of all sewer projects, and not unique to alternative collection systems. However, with these systems it has been particularly common for communities to react prior to becoming accurately informed. Either the use of pressure sewers is falsely glamorized or unduly criticized. Early public dissemination of accurate information is a critical role of the utility and the engineer.

Prior to construction, the property owners may be asked for any knowledge they may have of the location of the existing septic tank, drainfield, buried utilities, or property lines. The property owner may also have some role in the placement/location of the on-lot facilities. In locating these, thought should be given to property alteration plans, such as the widening of a driveway or the addition of a patio or deck.

Disruption to the community will be less for installation of pressure sewer mains than for conventional sewers, but disruption for installation of the services can be greater.

Throughout the planning-design-construction process, cooperation of all parties including homeowners results in a more easily accomplished project and lower costs.

Use of the system should comply with requirements of the user ordinance. Typical requirements include that the homeowner should not drive or build over the tank, and should protect the facilities from damage. Discharge of flammables, acids, excessive amounts of grease, sanitary napkins, or other non-wastewater items is discouraged. This requirement differs little from user ordinance requirements for conventional sewers. Proper use of the system results in lower user charges and improved reliability.

2.8.2 Sewer Utility Responsibilities

The utility should take seriously the need for early and accurate public address. On some larger community projects, opinion leaders of the community representing diverse geographical areas and varied cultural backgrounds have been sought. These people are invited to be special advisors to the utility, and in turn receive advance, more detailed information than is possible to disseminate at large public meetings. The personal contact they have with their neighbors can transfer information more meaningfully than is possible otherwise.

While maintenance and operation of a pressure sewer may not be more difficult than that of a conventional sewer, the technology is less well known. The utility should have the flexibility and talent required to adapt to unfamiliar practices. A degree of long-term commitment is required. The regulatory agency may want assurance of the utility's capabilities, to encourage their use of alternative sewers.

Tactful public relations are important, as they are with any utility function. Personnel in contact with the public become the utility's ambassadors. Selection of personnel should be made accordingly, and special training and ongoing support may be advised.

Detailed daily records should be kept of maintenance functions, and a summary report should be made annually. This report should quantify the maintenance requirements and make recommendations for project improvements. Involvement of the maintenance forces is required. Continuing involvement of the design engineer will close the loop between planning, design, construction, operation and maintenance, and will result in improved future designs.

The utility should be capable of responding to whatever routine or emergency needs may be presented.

2.9 References

When an NTIS number is cited in a reference, that reference is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

1. Clift, M.A. *Experience with Pressure Sewage.* ASCE-SED, 94(5):865, 1968.

2. *Combined Sewer Separation Using Pressure Sewers.* ASCE. FWPCA Report ORD-4, 1969.

3. Carcich, I.G. Hetling, L.J., and R.P. Farrell. *A Pressure Sewer Demonstration.* EPA Number R2-72-091, 1972.

4. Hendricks, G.F. and S.M. Rees. *Economical Residential Pressure Sewage System with No Effluent.* EPA/600/2-75/072, 1975.

5. Mekosh,G and D. Ramos. *Pressure Sewer Demonstration at the Borough of Phoenixville, Pennsylvania.* EPA Number R2-73-270, 1973.

6. Eblen, J.E. and L.K. Clark. *Pressure and Vacuum Sewer demonstration Project - Bend, Oregon.* EPA/600/2-78/166, NTIS No. PB287-146, 1978.

7. *Alternatives for Small Wastewater Treatment Systems.* EPA/625/4-77/011, NTIS No. PB299608. U.S. Environmental Protection Agency, Cincinnati, OH, 1977.

8. Great Lakes - Upper Mississippi River Board of State Sanitary Engineers, Recommended Standards for Sewage Works, Health Education Service, Albany, NY. 1978.

9. Thrasher, David. *Design and Use of Pressure Sewer Systems. Lewis Publishers.* 1988.

10. Bennett, E., K. Linstedt and J. Felton. *Rural Home Wastewater Characteristics.* Proc. of the National Home Sewage Symposium, American Society of Agricultural Engineers, 1974.

11. Jones, E. *Domestic Water Use in Individual Homes and Hydraulic Loading of and Discharge from Septic Tanks.* Proc. of the National Home Sewage Disposal Symposium, American Society of Agricultural Engineers, 1974.

12. Environment-One Corporation. *Design Handbook, Low Pressure Sewer Systems Using Environment-One Grinder Pumps.* 1989.

13. Flanigan, L.J. and R.A. Cudnik. *State of the Art Review and Considerations for the Design of Pressure Sewer Systems.* Weil-McLain Company, Ashland, Ohio, 1974.

14. Watson, K.S., Farrell, R.P. and J.S. Anderson. *The Contribution from the Individual Home to the Sewer System.* JWPCF 39(12):2039-2054, 1967.

15. Fair, G.M. and J.C. Geyer. *Water Supply and Wastewater Disposal.* J.Wiley & Sons, New York, NY, 1954.

16. Brinley, R.K., Olmstead, R.D. and S.M. Wilkinson. *Design Manual for Pressure Sewer Systems.* Peabody Barnes Inc., Mansfield, Ohio, 1982.

17. Conery, W.J. *Pressure Sewer Piping System Design.* F.E. Myers Co., Ashland, Ohio, 1981.

18. *Minimum Velocities for Sewers.* Journal Boston Society of Civil Engineers, 29(4):286, 1942.

19. Uni-Bell Plastic Pipe Association. *Handbook of PVC Pipe.* 1982.

21. International Association of Plumbing and Mechanical Officials, "Uniform Plumbing Code", 1985.

20. Cooper, B.J. *Buried Pipes in Frozen Soil.* In: Appropriate Wastewater Management Technologies for Rural Areas Under Adverse Conditions, D.H. Waller and A.R. Townshend, eds., Tech. Press, TUNS, Halifax, N.S., CANADA 1987.

22. Kim, S.W. Indiana State Board of Health I/A Newsletter, No. 5, Feb. 1981.

23. Weibel, S.R., et al. *Studies on Household Sewage Disposal Systems, Parts 1, 2, and 3.* U.S. Public Health Service Publications, 1949 - 1954.

24. Winneberger, J.H. *Septic-Tank Systems, A Consultant's Toolkit.* Butterworth Publishers, 1984.

25. Baumann, E.R. and H.E. Babbitt, H.E. *An Investigation of the Performance of Six Small Septic Tanks.* University of Illinois Engineering Experiment Station, Bulletin Series No. 409, Vol. 50, No. 47, February 1953.

26. *Design Manual: Onsite Wastewater Treatment and Disposal Systems.* EPA/625/1-80/012, NTIS No. PB83-219907, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1980.

27. *Handbook: Septage Treatment and Disposal.* EPA/625/6-84/009, NTIS No. PB88-184015. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1984.

28. Siegrist, R.L., Anderson, D.L. and J.C. Converse. *Commercial Wastewater On-Site Treatment and Disposal.* Proceedings of the 4th National Home Sewage Symposium, ASAE, Proc. 07-85, 1985.

29. *Design Manual: Odor and Corrosion Control in Sanitary Sewerage Systems and Treatment Plants.* EPA/625/1-85/018, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1985.

30. Farrell, R.P. *Operating and Maintenance Experience with Some Pressure Sewer Systems.* In: Proc. of the Fourth National Conference, Individual Onsite Wastewater Systems, National Sanitation Foundation, 1977.